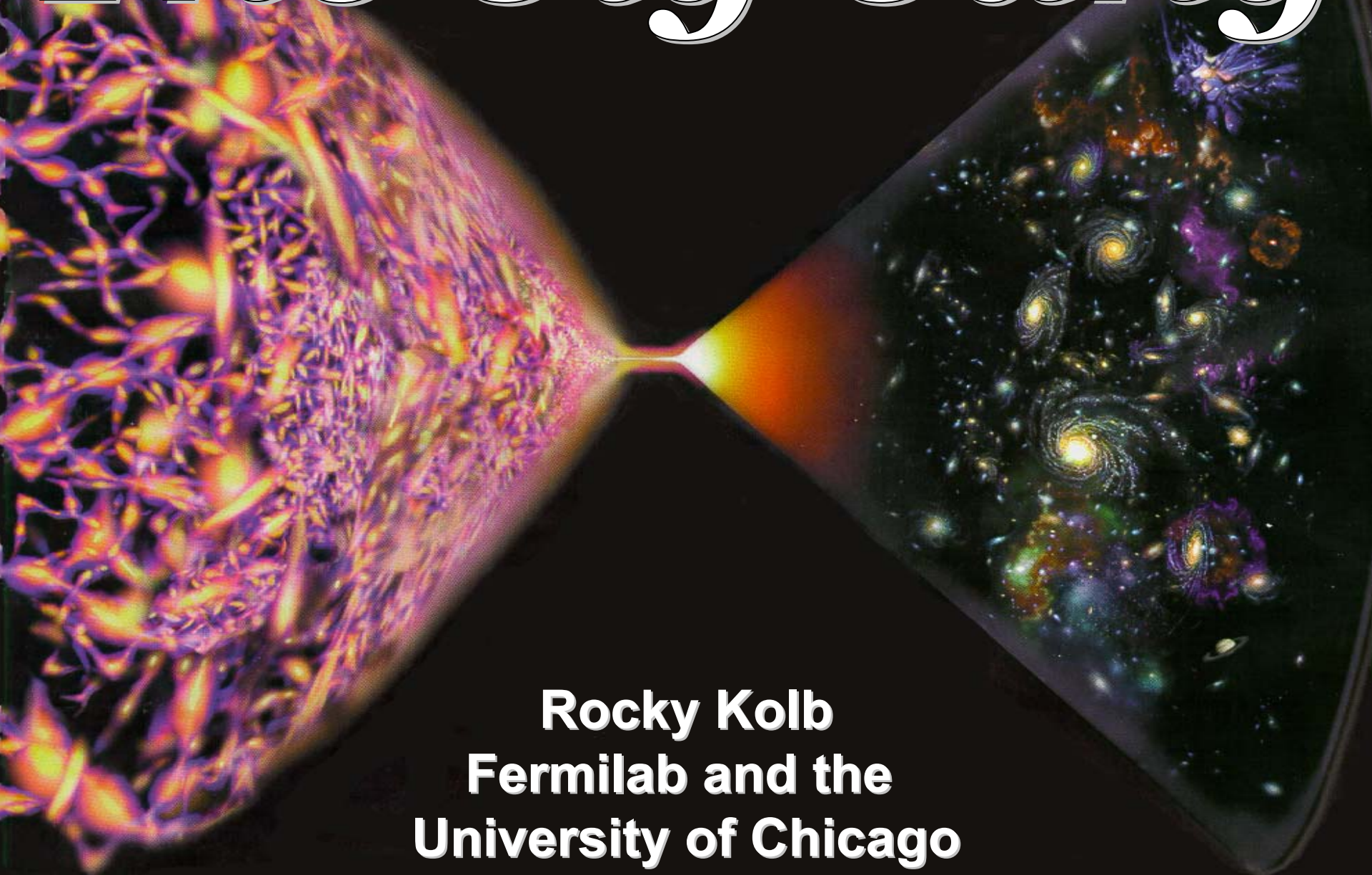
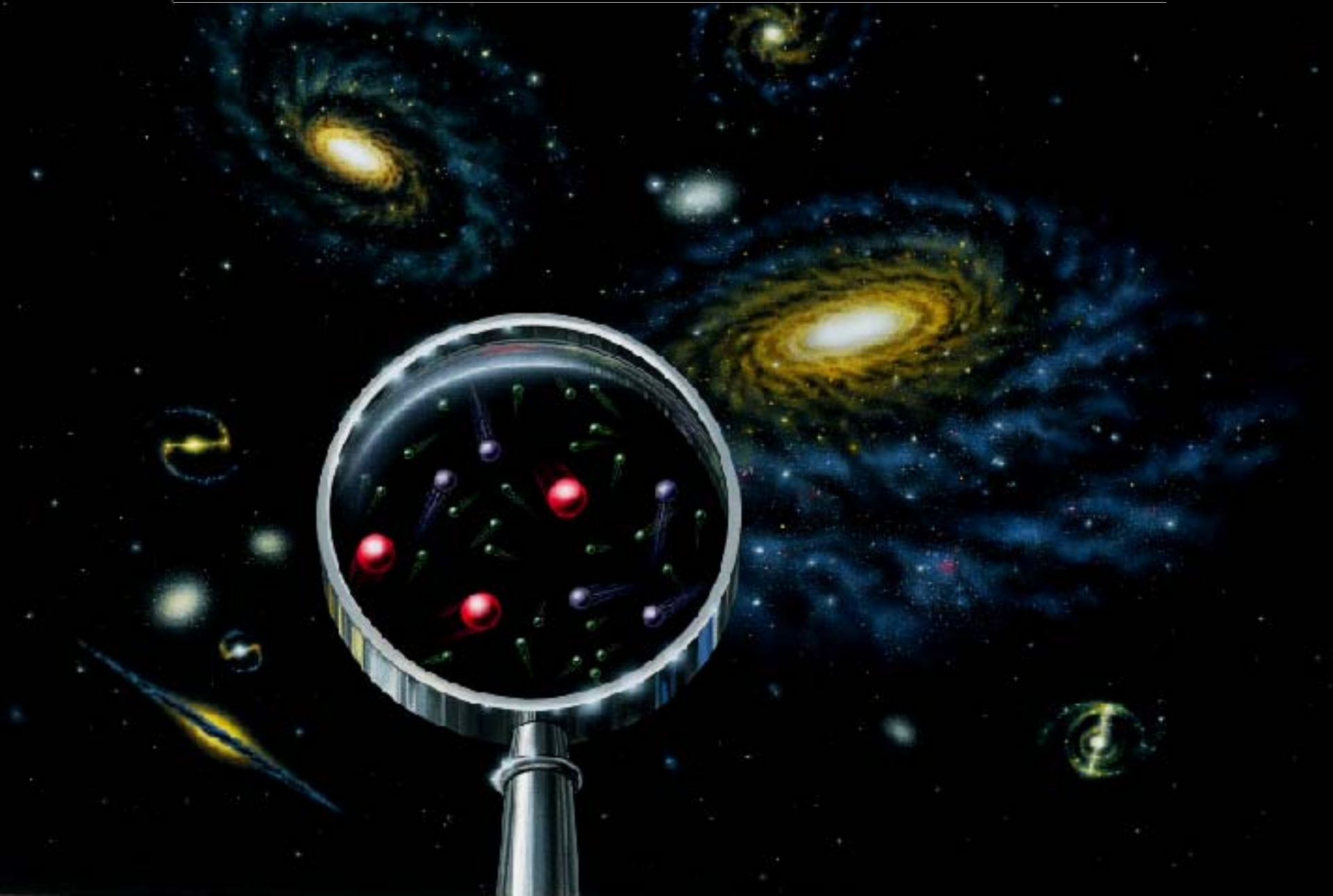


# *The big bang*



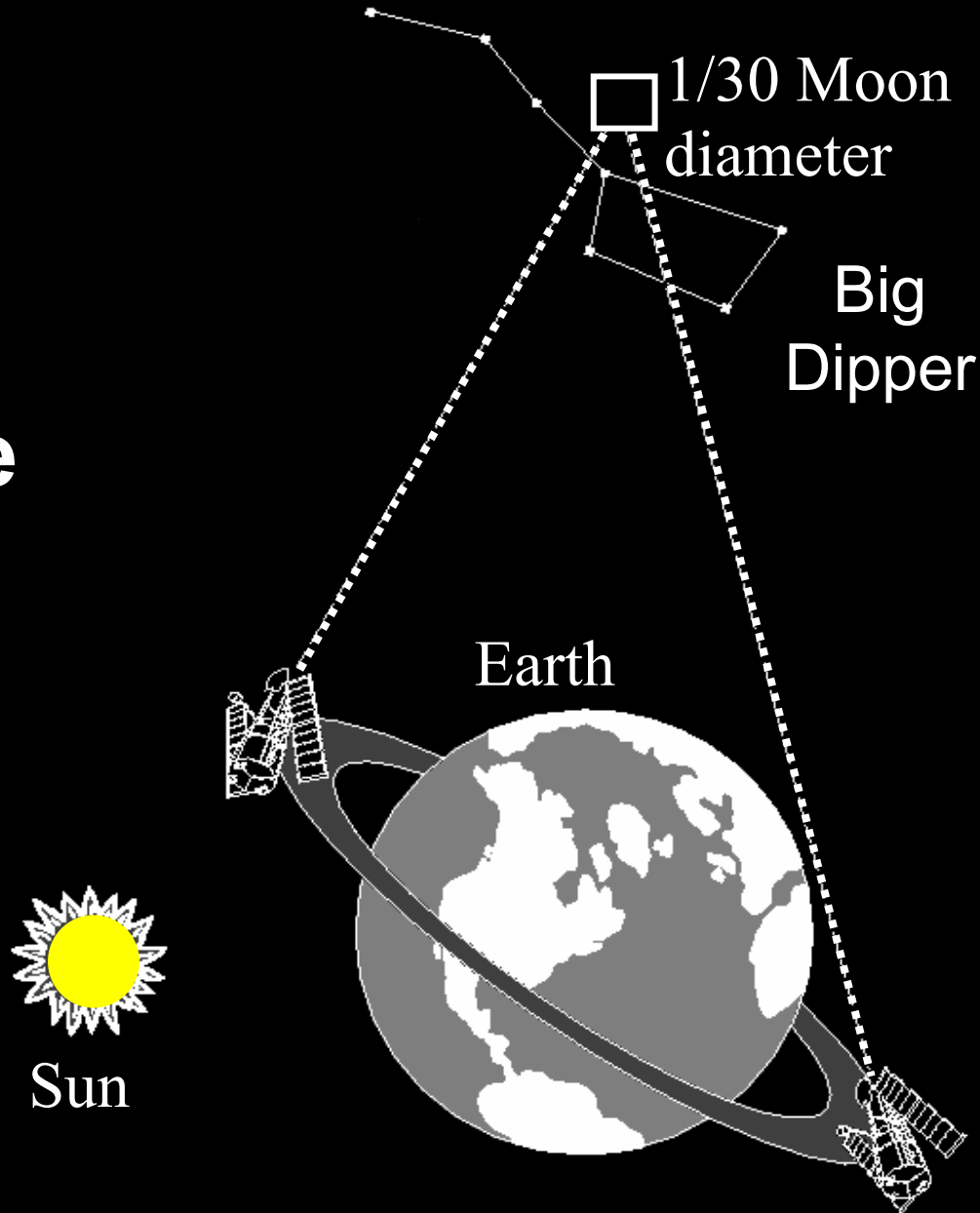
**Rocky Kolb  
Fermilab and the  
University of Chicago**

# *Inner space / Outer space*



# *Outer Space - The Cosmos*

## The Hubble Deep Field





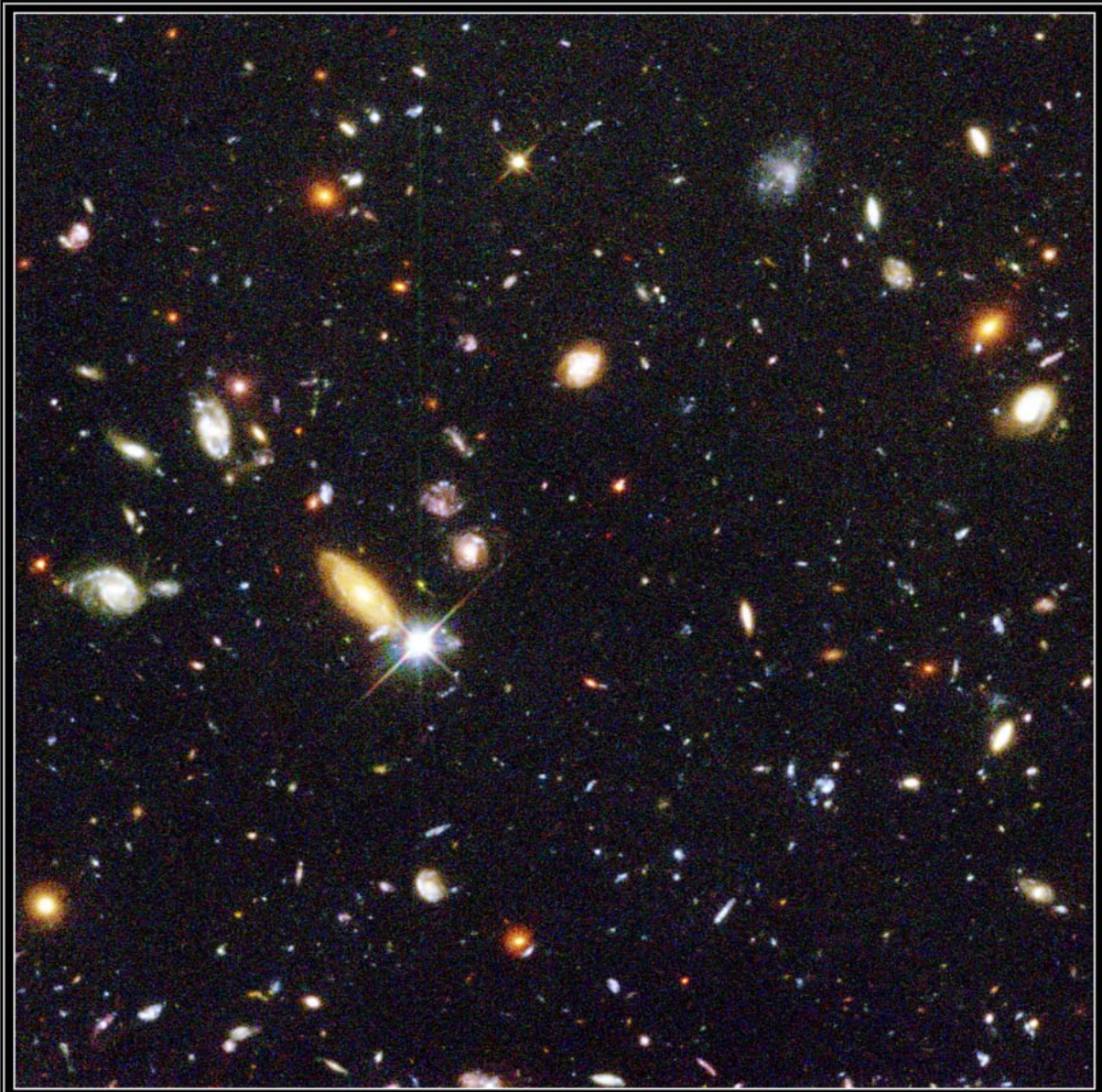
# *Hubble deep field*

## UNIVERSE OF GALAXIES

3000  
here



50 billion  
over entire  
sky





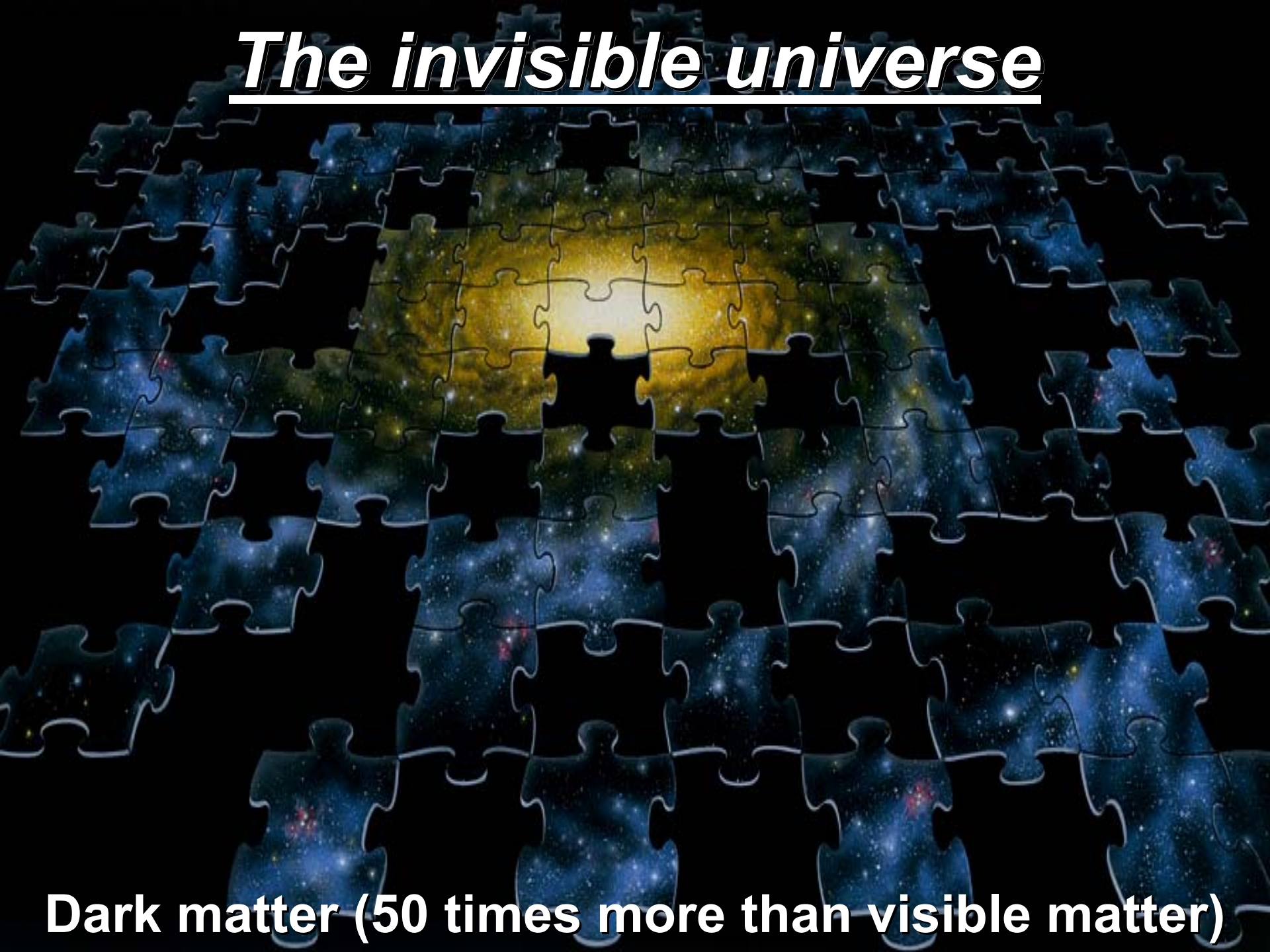
# *The visible universe*



**M63**

**Galaxies**

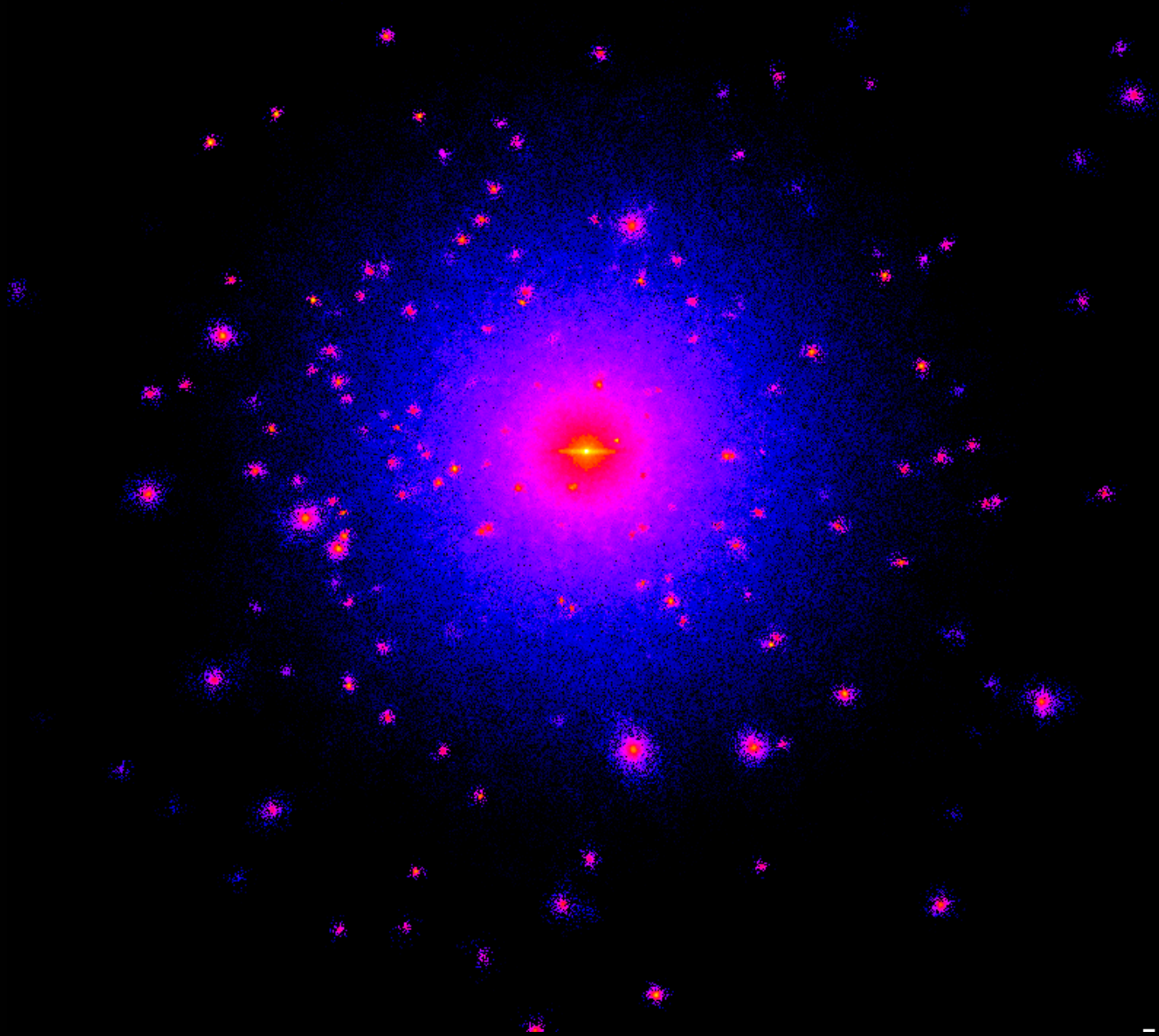
# *The invisible universe*



**Dark matter (50 times more than visible matter)**

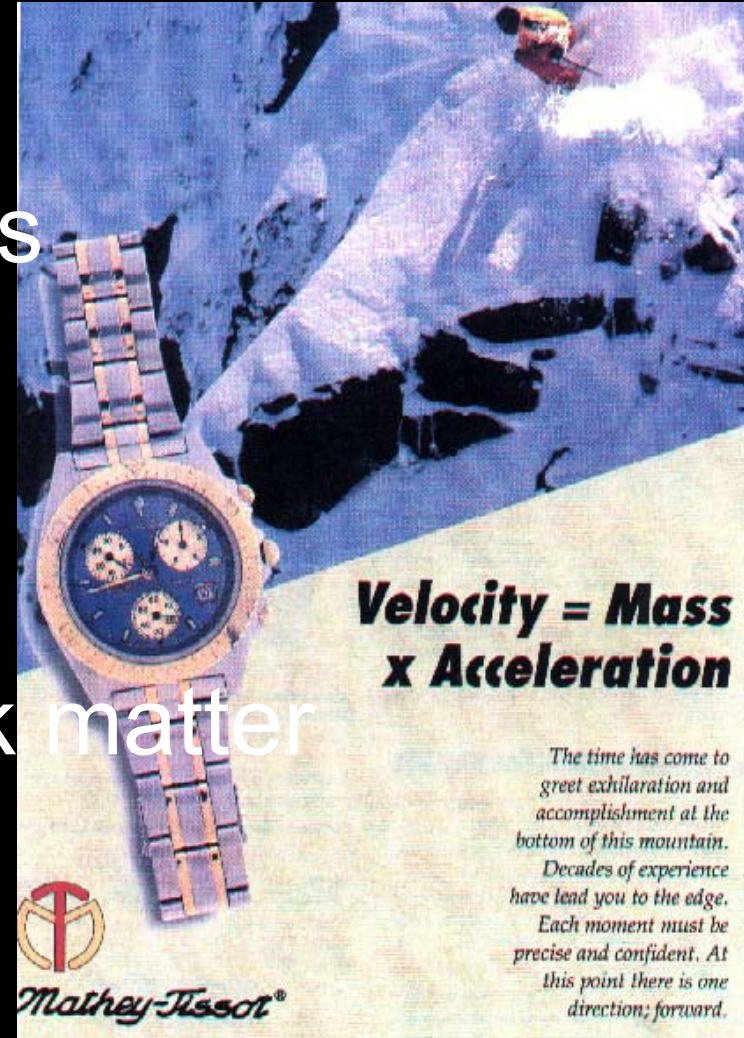


***If we could “see” dark matter***



# Dark matter?

- Modified Newtonian dynamics
- Planets
- Mass disadvantaged stars
  - brown
  - red
  - white
- Black holes
- Nonbaryonic particle dark matter





# Dark energy?

Space and time are related.

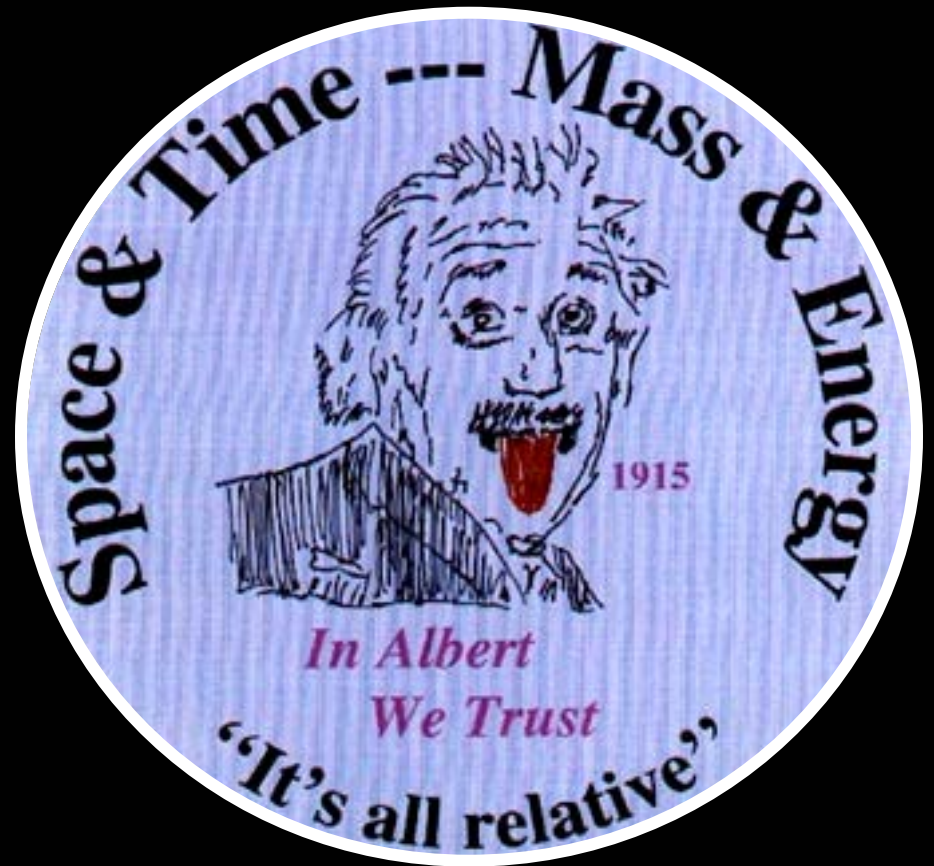
1905

Space is dynamical (curved, warped, bent).

1915

Empty space has a weight.

1917





*the weight of space*  
**Cosmological**  
**constant**  
**(dark energy)**

**1917** Einstein proposed cosmological constant.

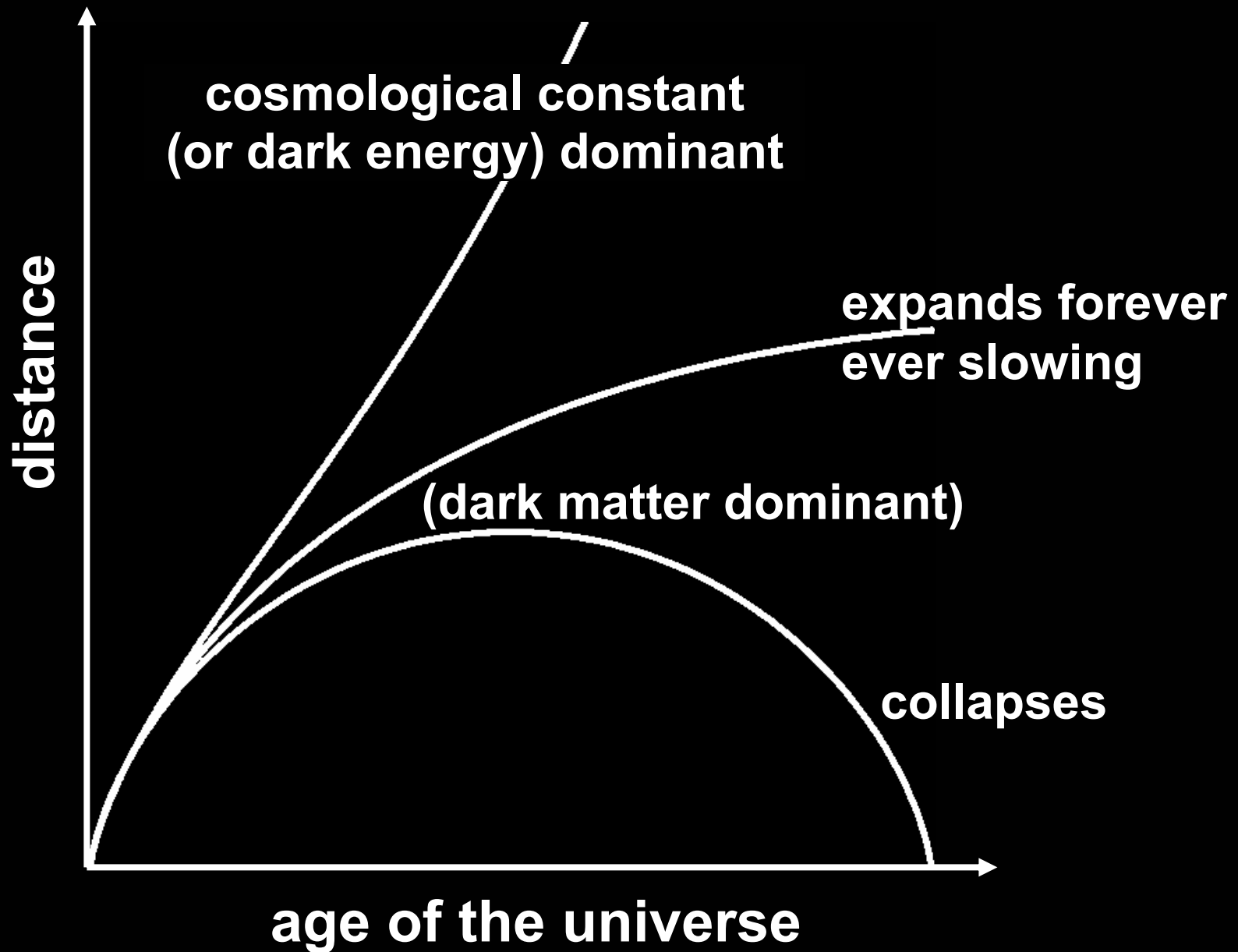
**1929** Hubble discovered expansion of the universe.

**1934** Einstein called it “my biggest blunder.”

**1998** Astronomers found evidence for it.

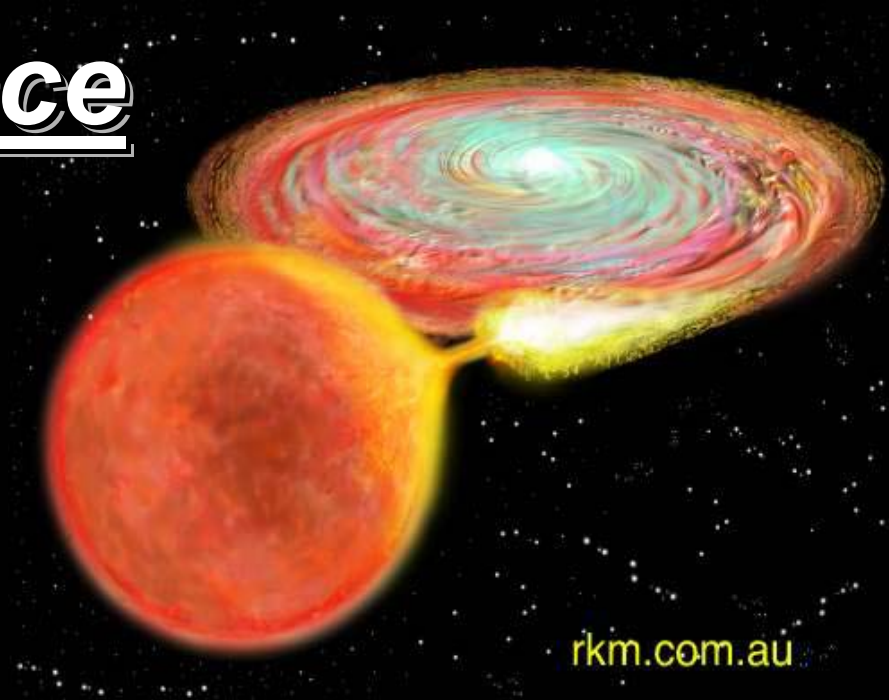


# **Cosmological constant (dark energy)**



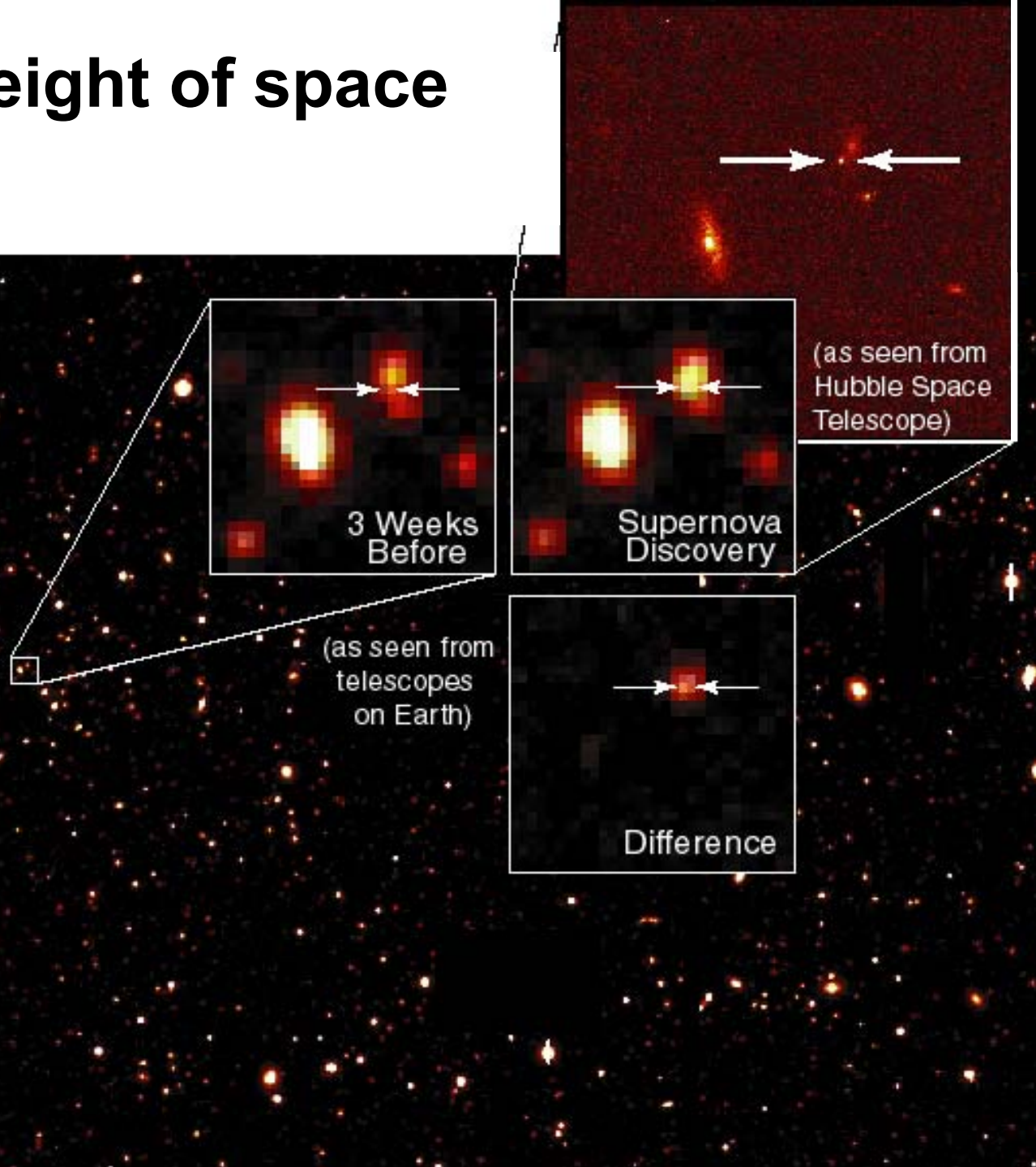
# *The weight of space*

## Supernovae





# The weight of space



# ***Cosmological constant (dark energy)***

**Mass density of space:**  $10^{-30} \text{ g cm}^{-3}$

**The unbearable lightness of nothing!**

***Cosmo-illogical constant?***



***Much ado about nothing***  
***(the vacuum)***

NOTHING is something!

NOTHING has energy!

NOTHING matters!

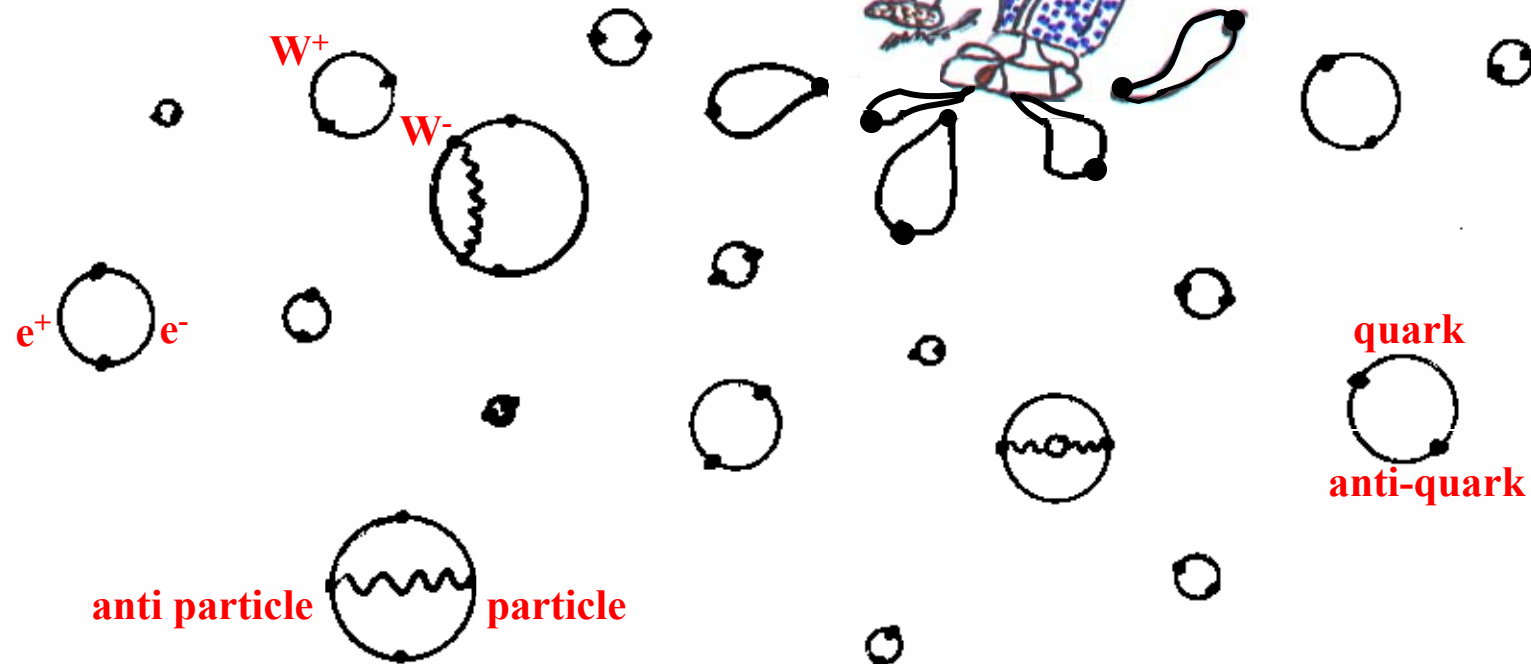
NOTHING changes!

# ***Quantum Uncertainty***

---

# ***and the Vacuum***

---

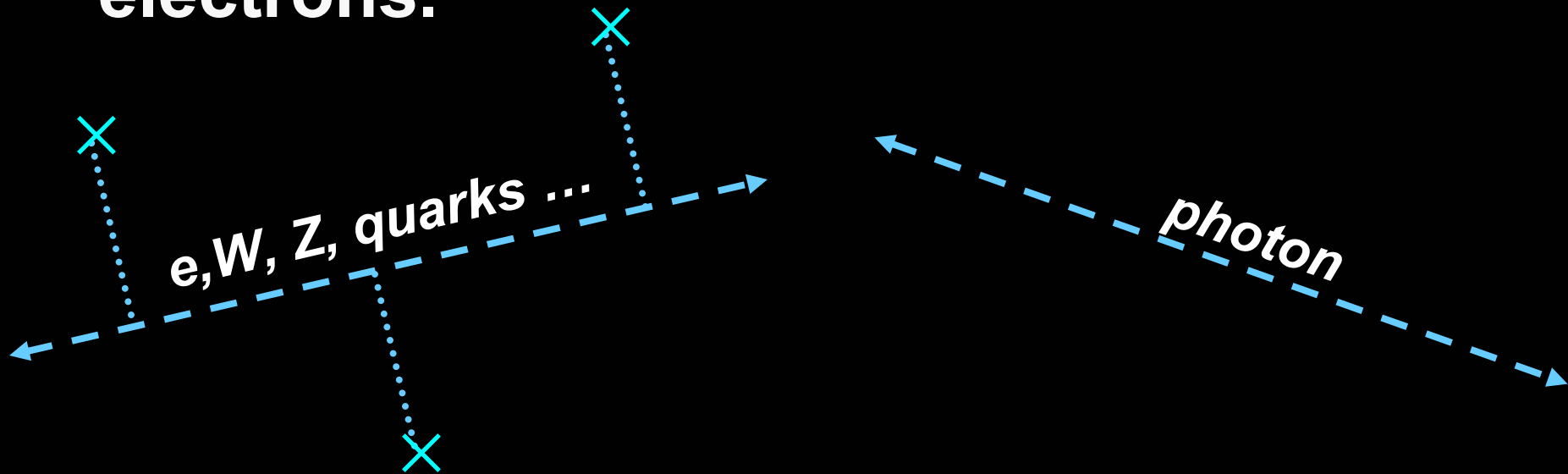


---

***Nothing is something!***

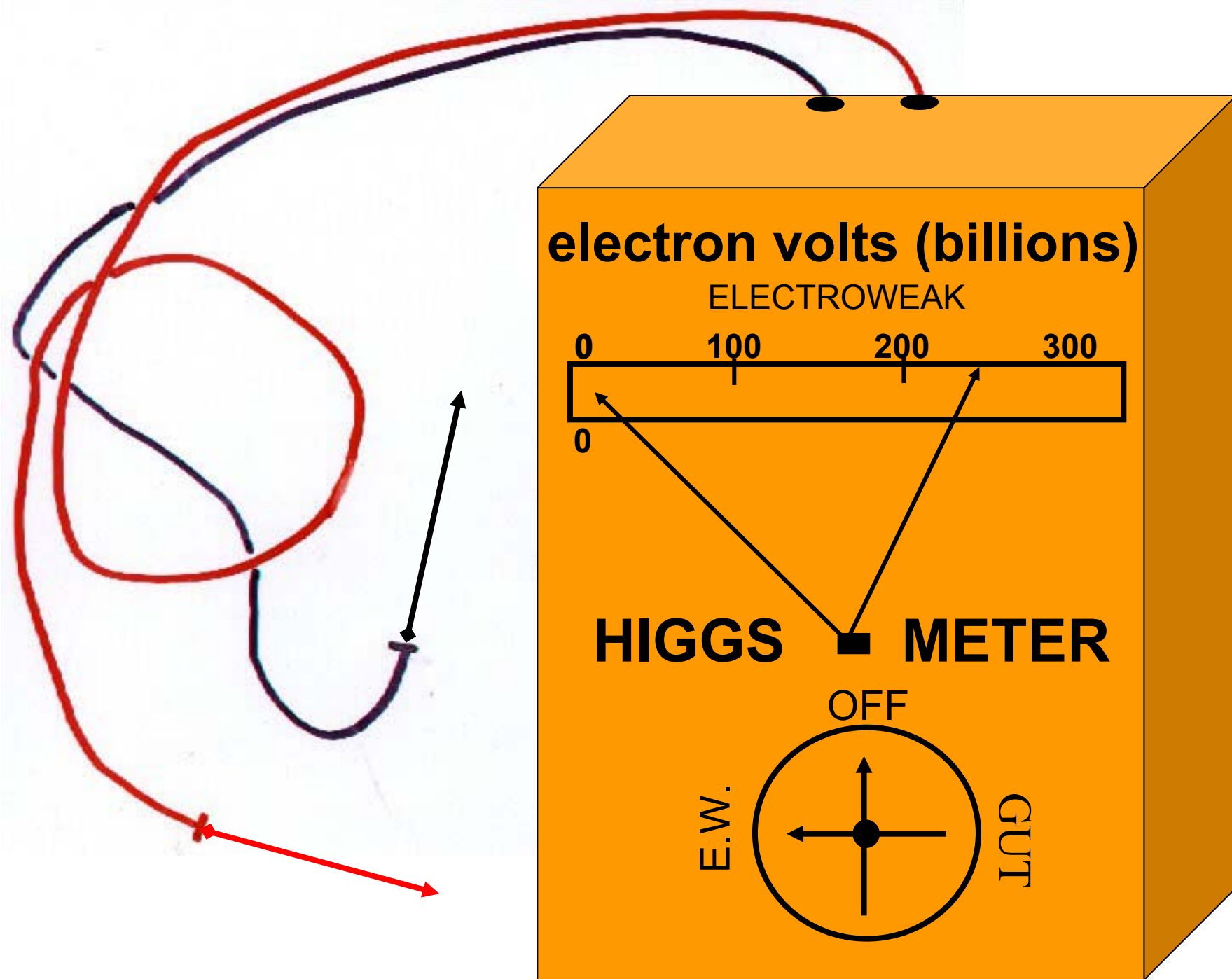
# *The Higgs potential*

- The vacuum has a “Higgs potential”
- Interaction with the Higgs field potential gives mass to particles like quarks and electrons.



*Nothing has energy:*

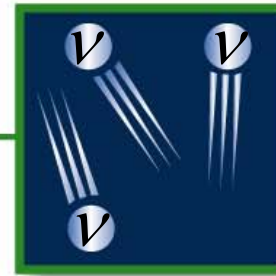




# **Cosmic Pie**



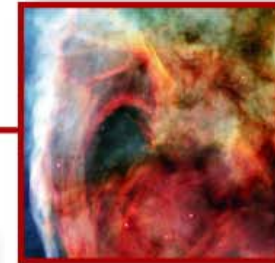
**Chemical Elements:  
(other than H & He) 0.03%**



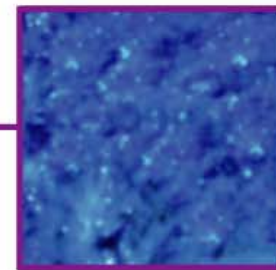
**Neutrinos:  
0.47%**



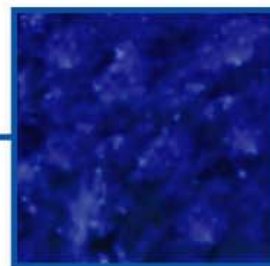
**Stars:  
0.5%**



**Free H  
& He:  
4%**

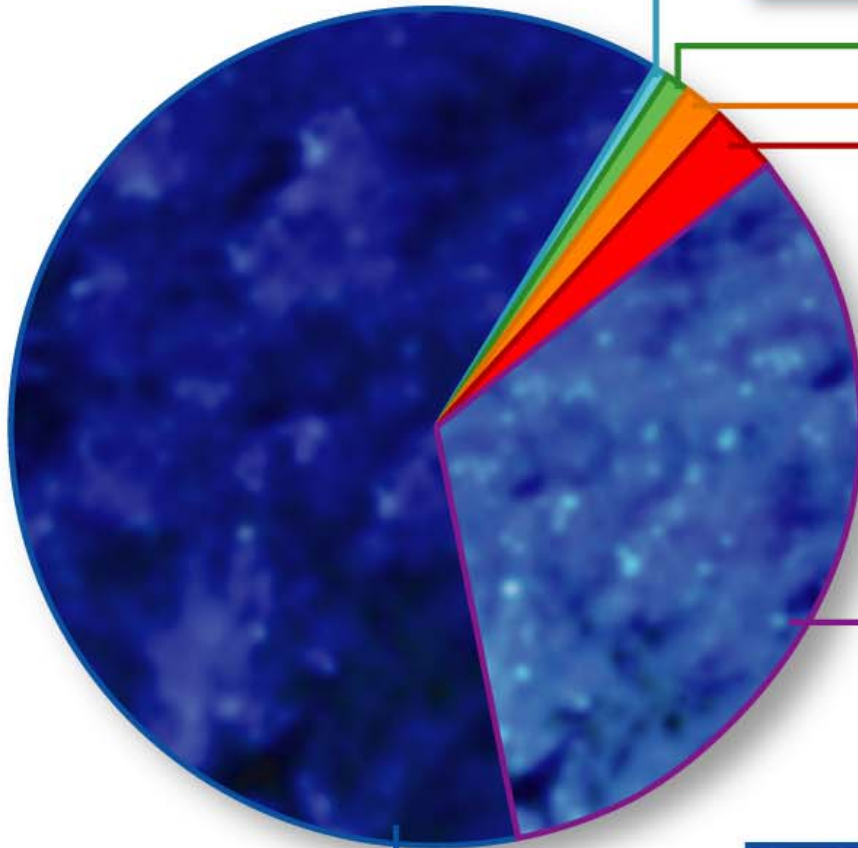


**Dark Matter:  
25%**

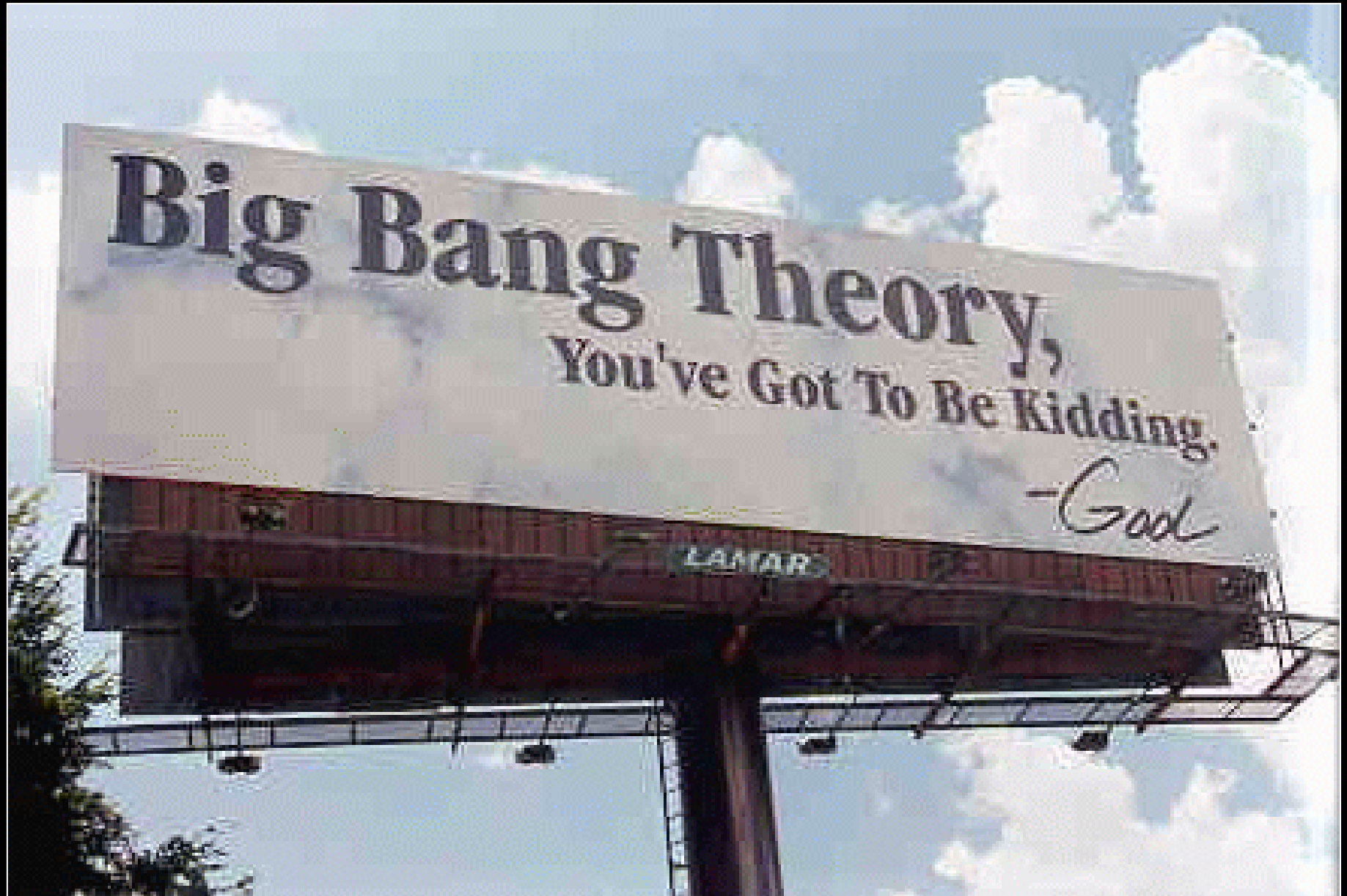


**Dark Energy:  
70%**

***Nothing  
matters!***



**Nothing can change!**





**Space expands.**

**Edwin Hubble  
1929**



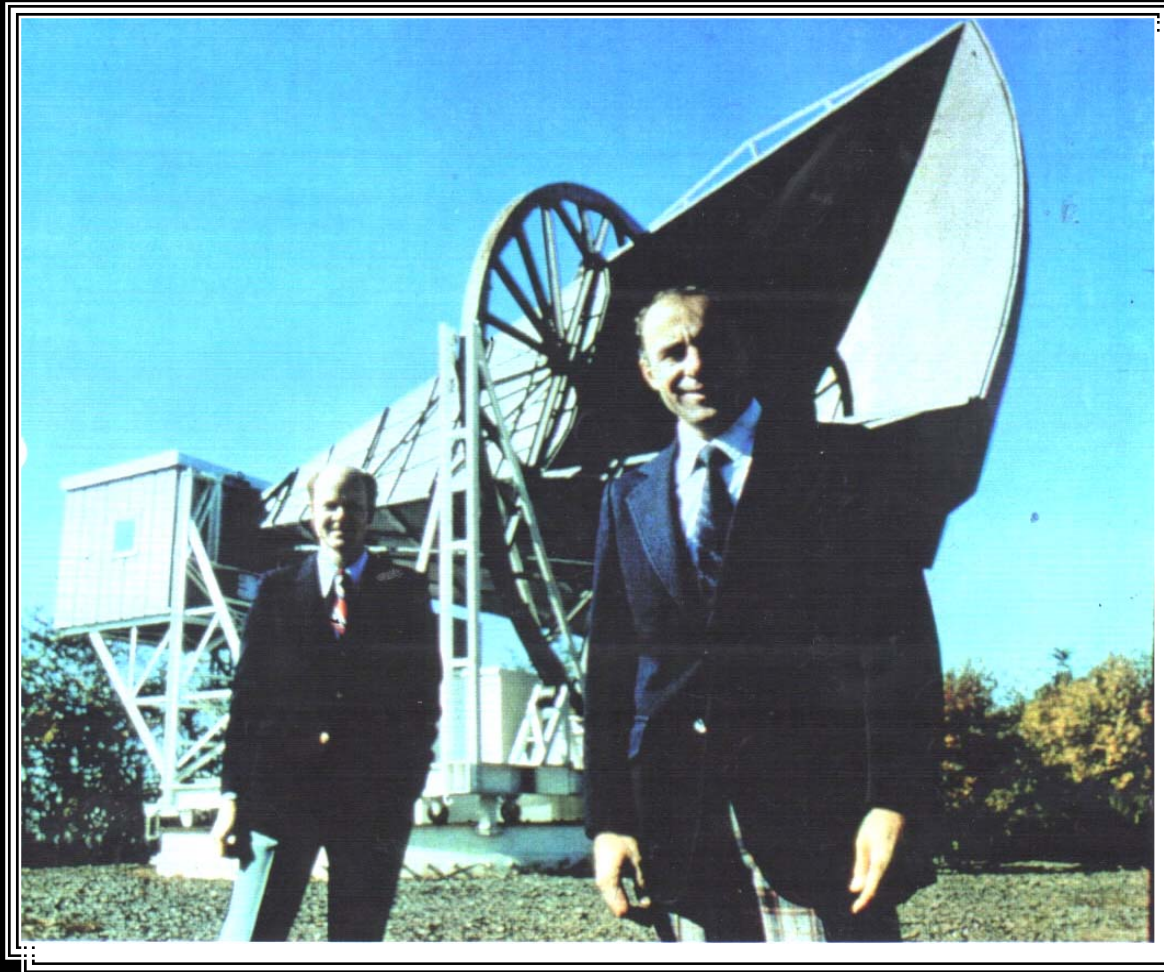
# *The University of Chicago*



**1909 National Champions**

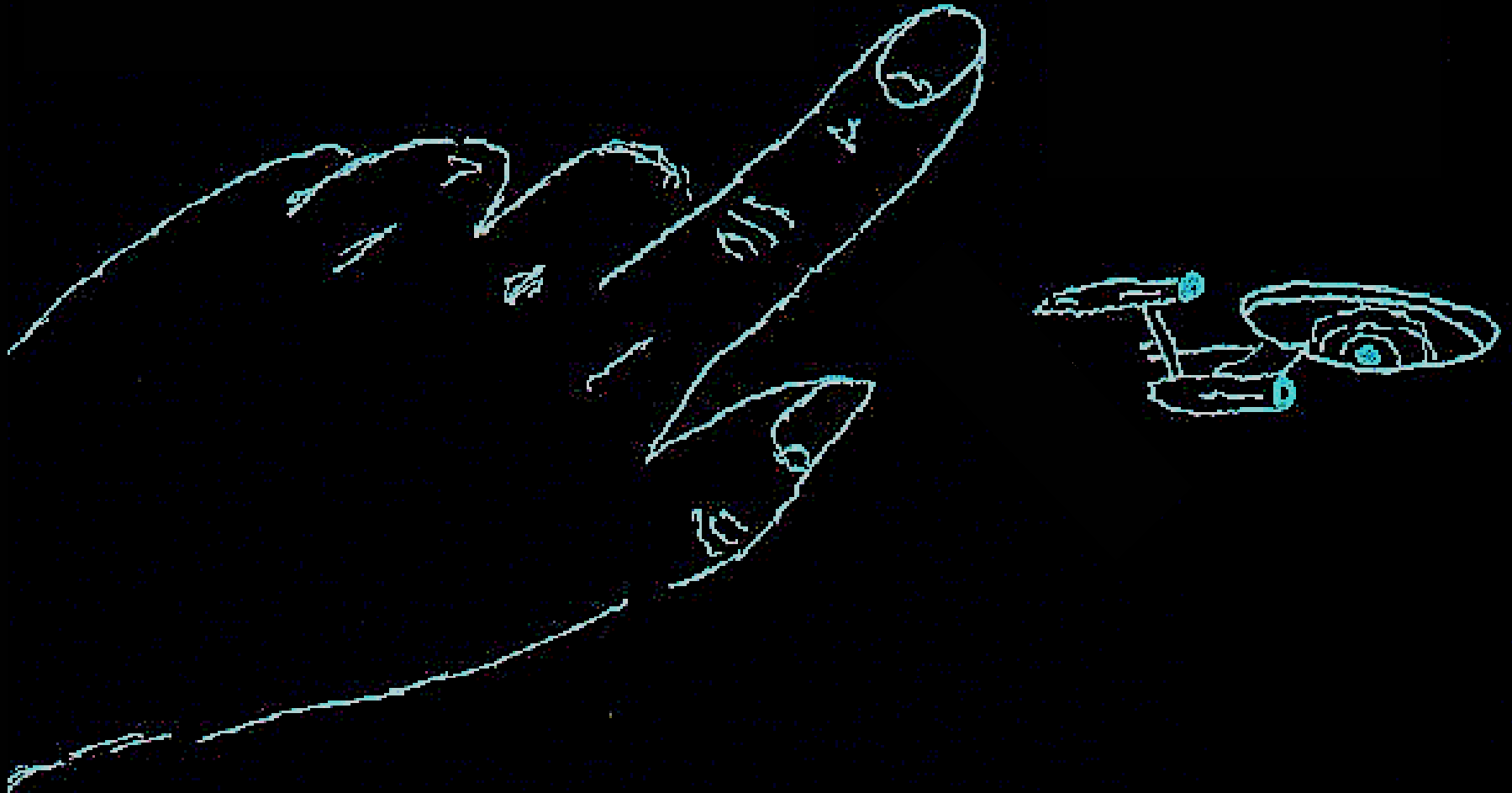
**The universe  
is radiant.**

**Arno Penzias  
Robert Wilson  
1965**





# ***Cosmic background radiation***



$$T = 3K = -454^{\circ} F$$

*Every cubic inch of space is a*

***MIRACLE!***

*- Walt Whitman*

- background radiation
- virtual particles
- Higgs potential
- dark matter
- dark energy

$T(^{\circ})$

Primordial soup

***Complete history***

***of the universe***

***(abridged)***

Neutrons  
Protons  
born

Nuclei  
(elements)  
born

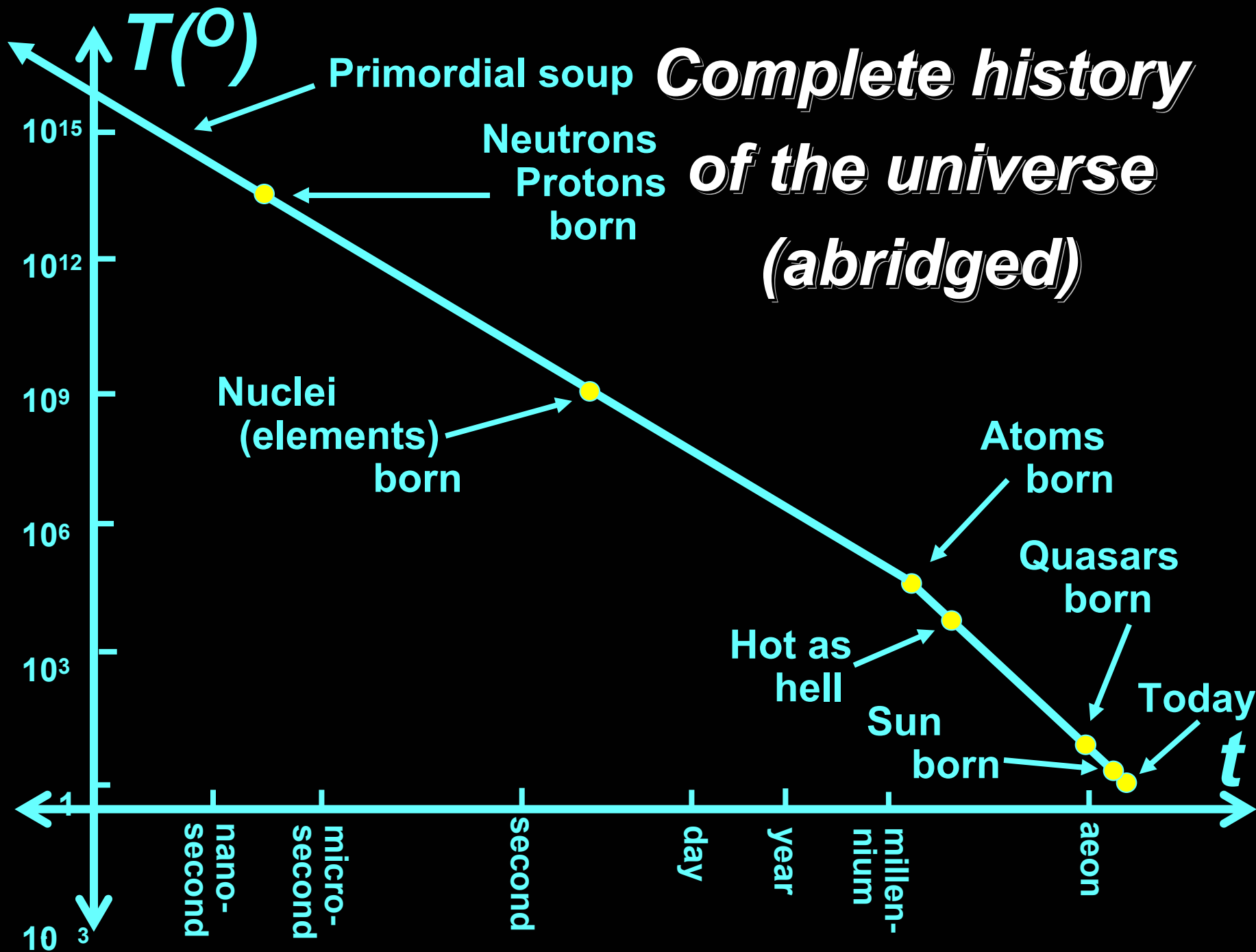
Atoms  
born

Quasars  
born

Hot as  
hell

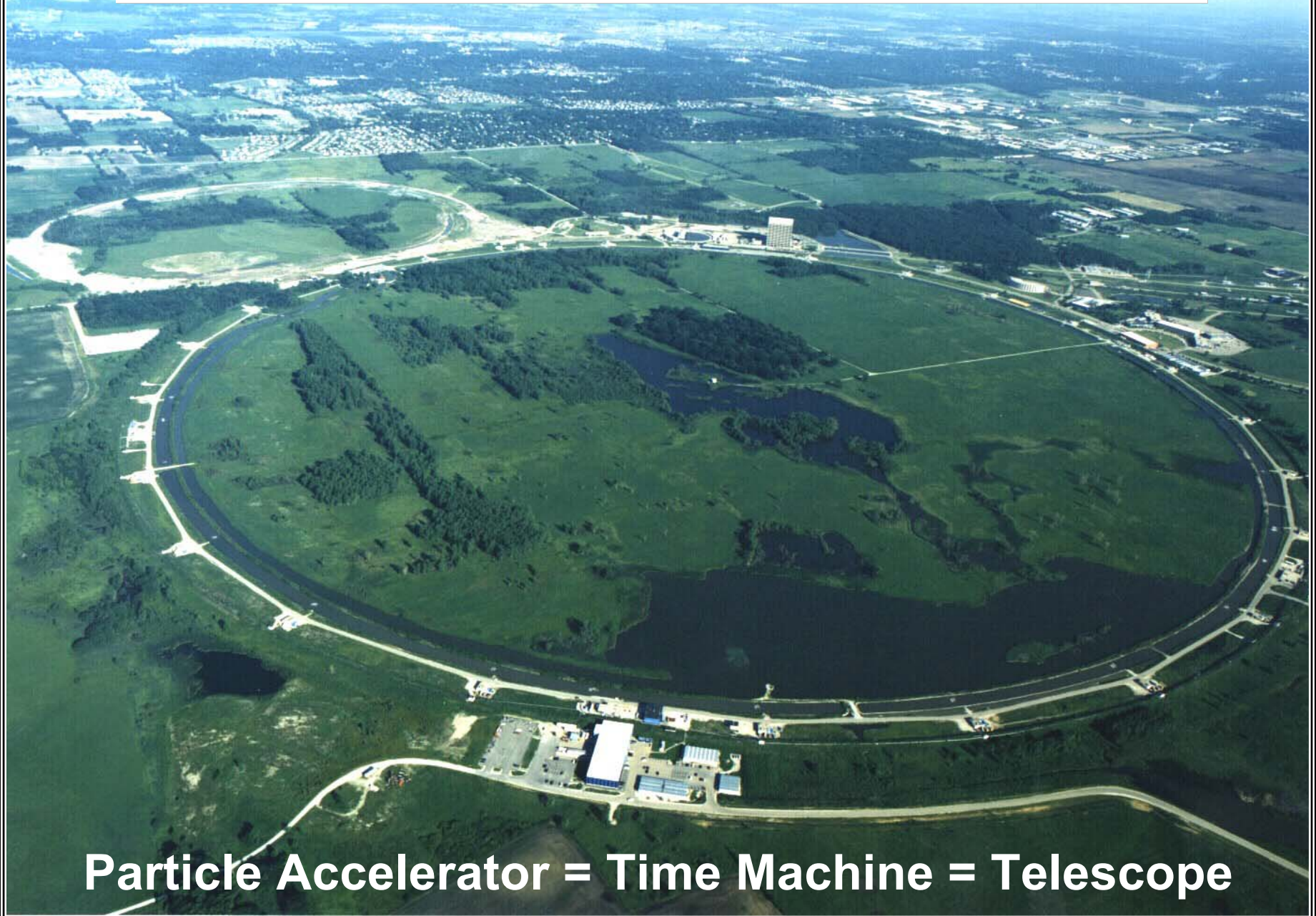
Sun  
born

Today





# **Inner Space - The Quantum**



**Particle Accelerator = Time Machine = Telescope**



*Fermilab's*



**Primordial**

**SOUP**



# *Primordial soup*

0.000 000 000 004 seconds AB

3,000,000,000,000,000°

## CONDENSED

in } 50 Earth masses in matter  
one } 50 Earth masses in antimatter  
can } + extra mountain of matter

## HOT

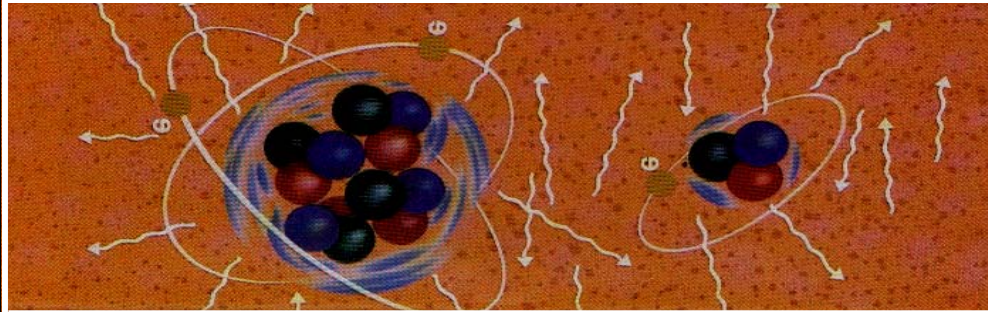
per } 10 billion years of total  
serving } energy output of sun

## INGREDIENTS

in every spoonful } every type of elementary particle

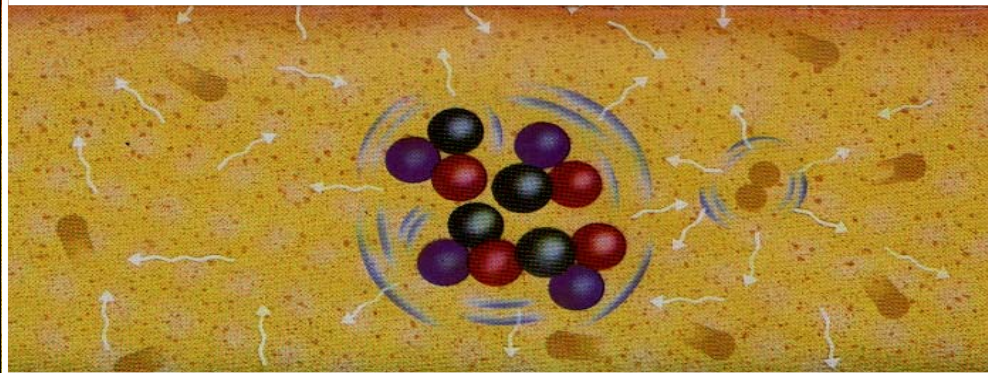


**300,000  
years**



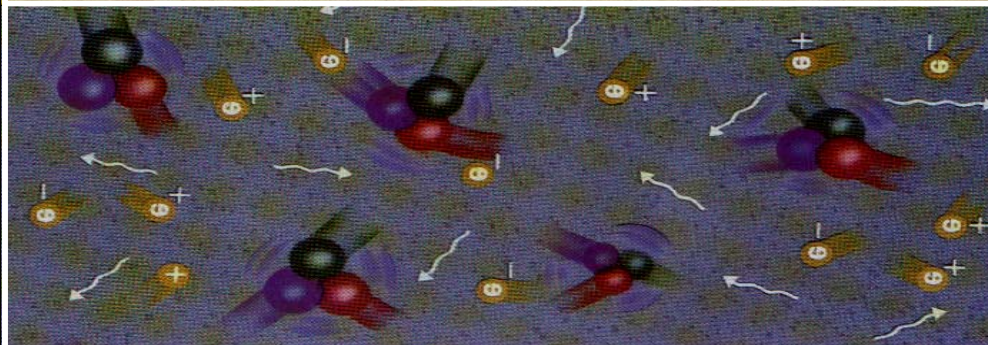
**atoms  
form**

**3  
minutes**



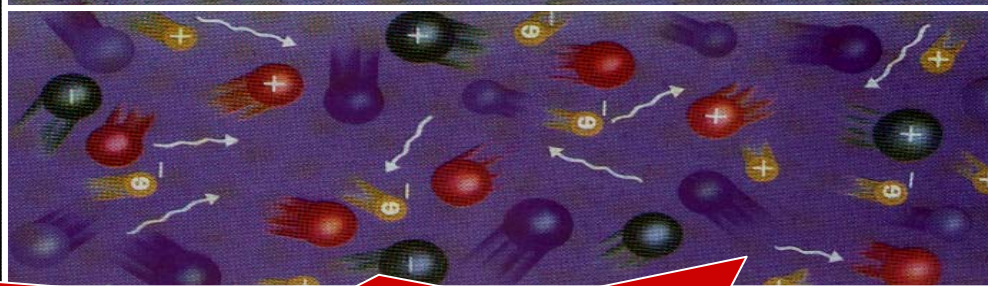
**nuclei  
form**

**1-micro  
second**



**neutrons  
protons  
form**

**4-pico  
seconds**



**primordial  
soup**

**BANG!**

# ***Periodic table - chemist***

H																	He
Li	Be											B	C	N	O	F	Ne
Na	Mg											Al	Si	P	S	Cl	Ar
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
Fr	Ra		Rf	Db	Sg	Bh	Hs	Mt	Uun	Uuu	Uub						
			La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu
			Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr

# ***Periodic table - cosmologist***

H

He

**Metals**

## *The Universe Today:*

73% Hydrogen ( $10^{-5}$  deuterium)

26% Helium ( $10^{-5}$   $^3\text{He}$ )

1% Metals

## *The Universe 3 minutes AB:*

76% Hydrogen ( $10^{-5}$  deuterium)

24% Helium ( $10^{-5}$   $^3\text{He}$ )

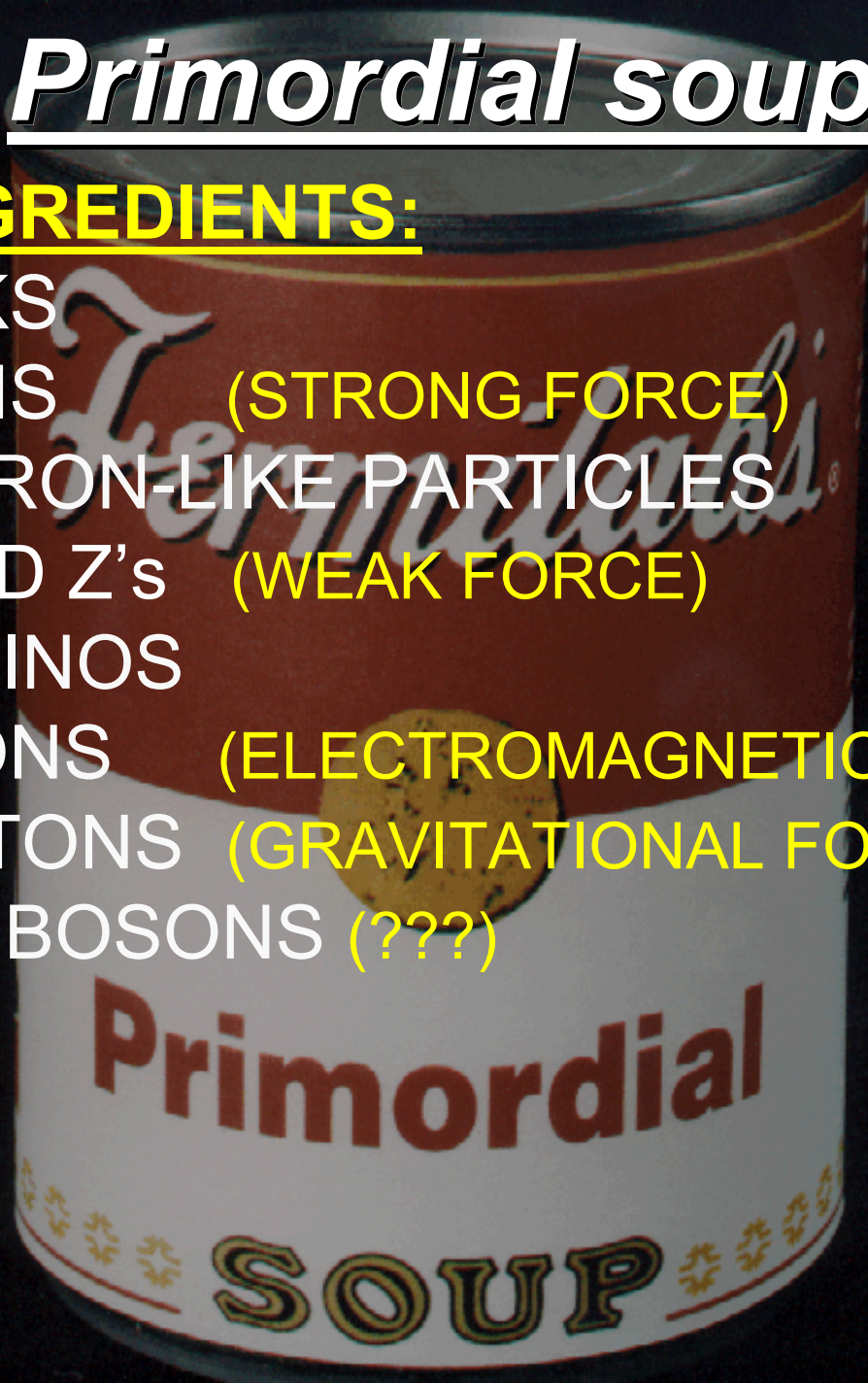
$10^{-8}\%$  Lithium



# *Primordial soup*

## KNOWN INGREDIENTS:

- 56% QUARKS
- 16% GLUONS (STRONG FORCE)
- 9% ELECTRON-LIKE PARTICLES
- 9% W's AND Z's (WEAK FORCE)
- 5% NEUTRINOS
- 2% PHOTONS (ELECTROMAGNETIC FORCE)
- 2% GRAVITONS (GRAVITATIONAL FORCE)
- 1% HIGGS BOSONS (???)



# *Primordial soup*

## KNOWN INGREDIENTS:

56% QUARKS  
16% GLUONS (STRONG FORCE)  
9% ELECTRON-LIKE PARTICLES  
9% W's AND Z's (WEAK FORCE)  
5% NEUTRINOS  
2% PHOTONS (ELECTROMAGNETIC FORCE)  
2% GRAVITONS (GRAVITATIONAL FORCE)  
1% HIGGS BOSONS (???)

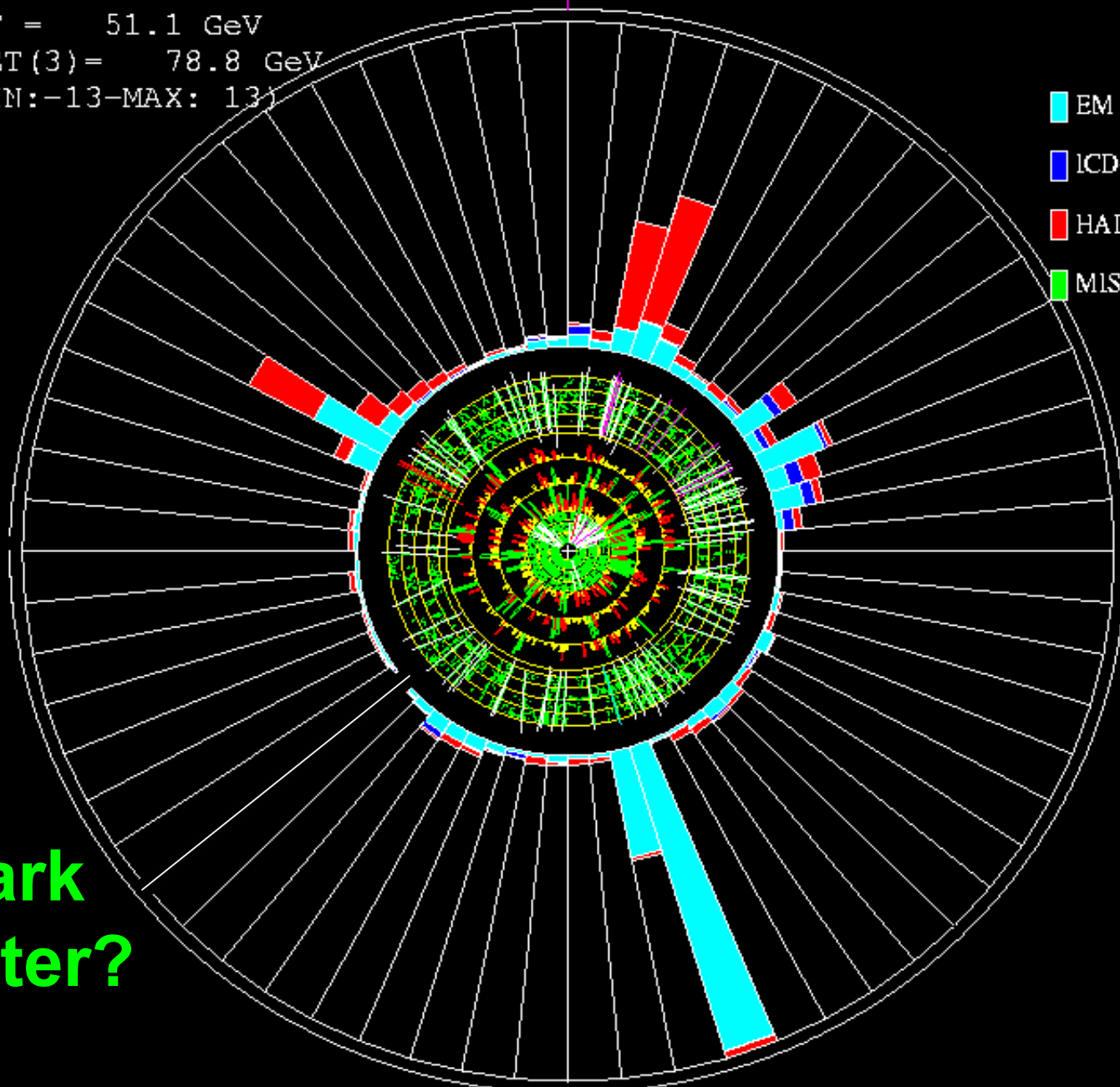
## SECRET INGREDIENT:

DARK MATTER



Max ET = 51.1 GeV  
 MISS ET(3) = 78.8 GeV  
 ETA(MIN:-13-MAX: 13)

EM  
 ICD+MG  
 HAD  
 MISS ET



Dark  
 Matter?

\_MUON  
 \_ELEC  
 \_TAUS  
 \_VEES  
 \_OTHER

# the Neutrinos



**Ballard Firehouse**

January 26

February 9

\$3.00

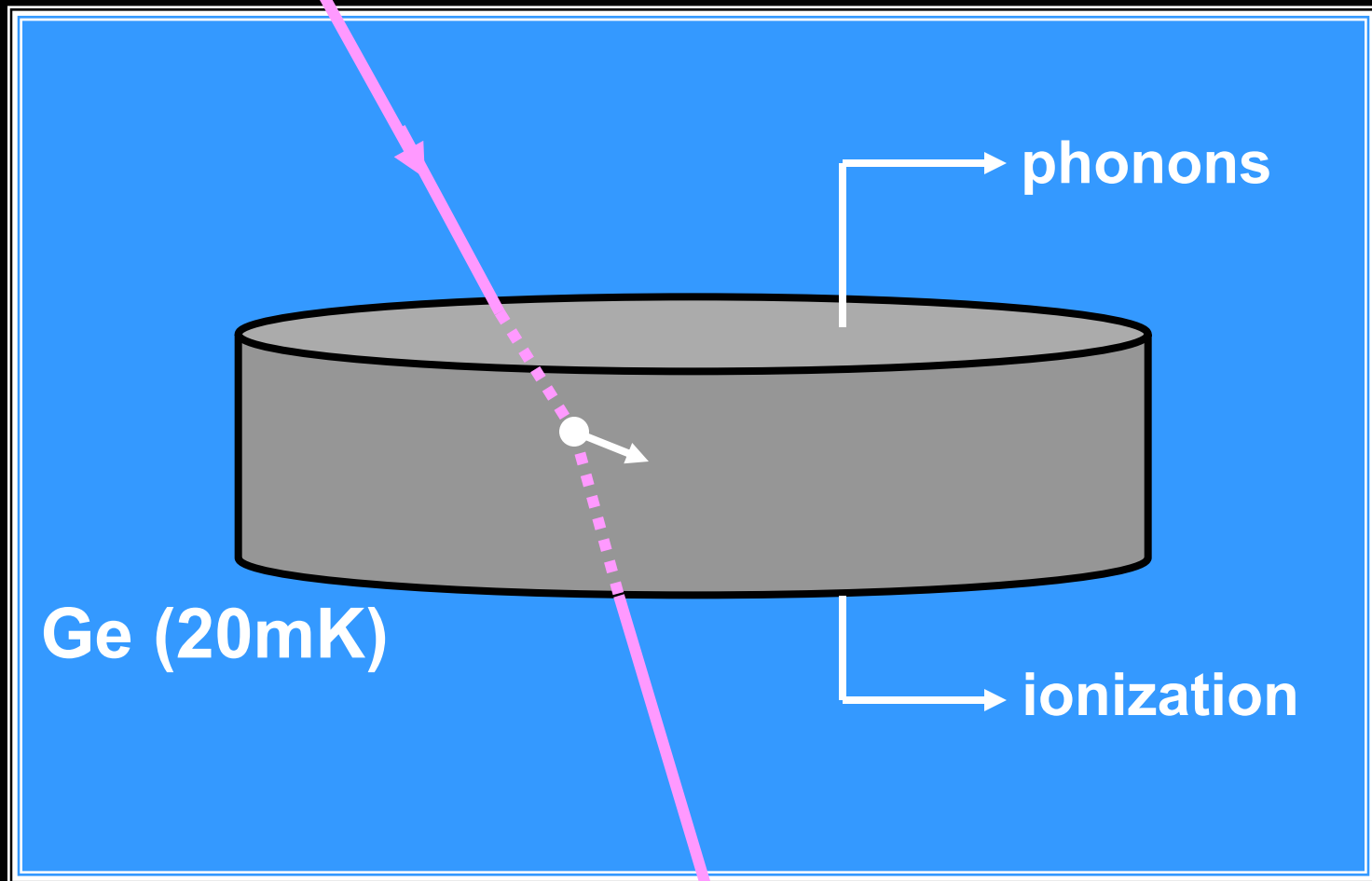


# MINOS



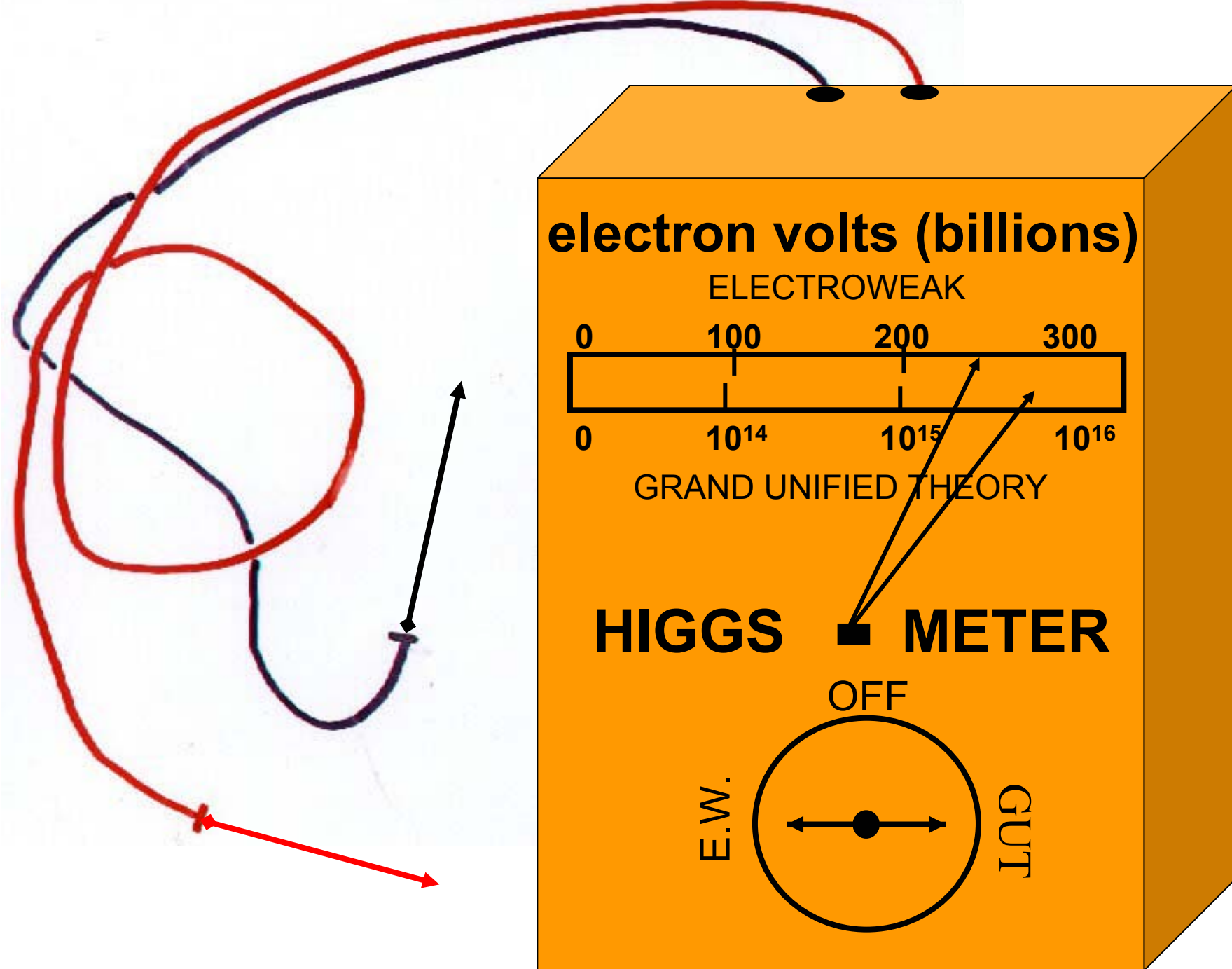
also CERN → Gran Sasso

**WIMP ( $300 \text{ km s}^{-1}$ )**



***Before primordial soup?***

**Nothing!**

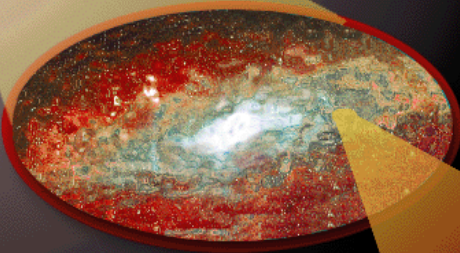




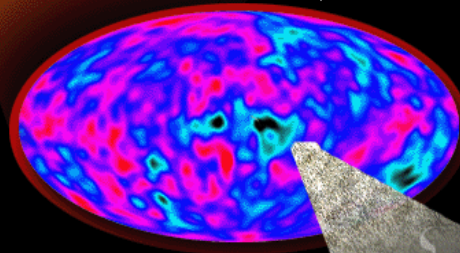
# *Imprint of Inflation*

*BIG BANG*

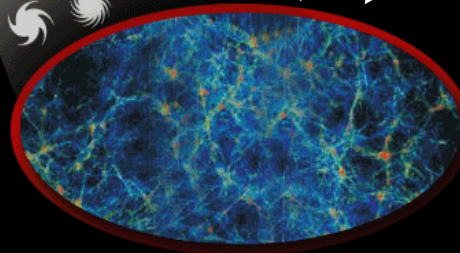
Inflation  
Big Bang plus  
 $10^{-32}$  seconds



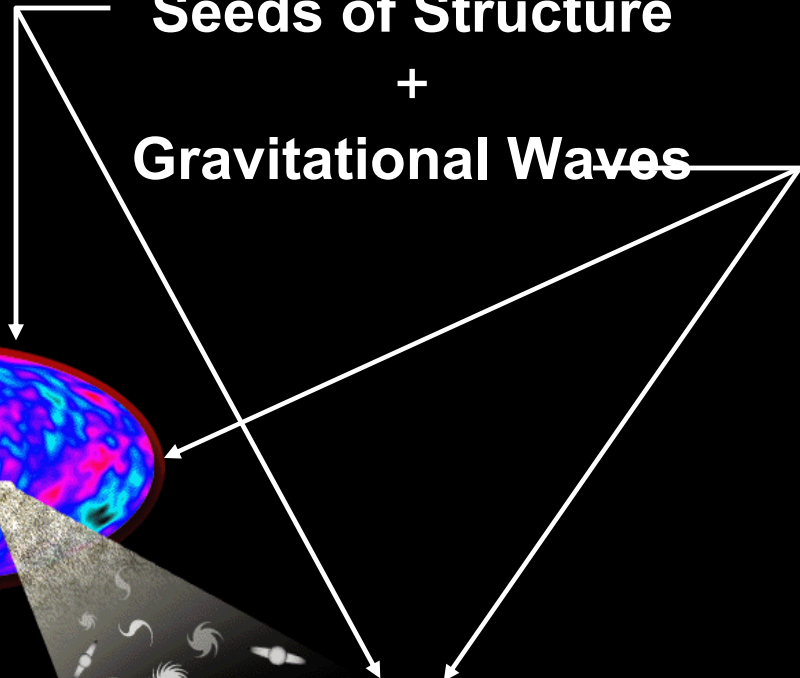
Big Bang plus  
380,000 Years



Big Bang plus  
14 Billion Years



Seeds of Structure  
+  
Gravitational Waves



# *An early particle cosmologist*



**Erwin Schrödinger**

1938-1939: Graz  $\longrightarrow$  Vatican  $\longrightarrow$  Gent, Belgium  $\longrightarrow$  Dublin

# ***The proper vibrations of the expanding universe***

**Erwin Schrödinger (1939)**

## **Introduction:**

production of matter, merely by expansion [of the universe],... Alarmed by these prospects, I have examined the matter in more detail.”

## **Conclusion:**

“... There will be a mutual adulteration of [particles] in the course of time, giving rise to ... the ‘alarming phenomenon’...”

# ***The proper vibrations of the expanding universe***

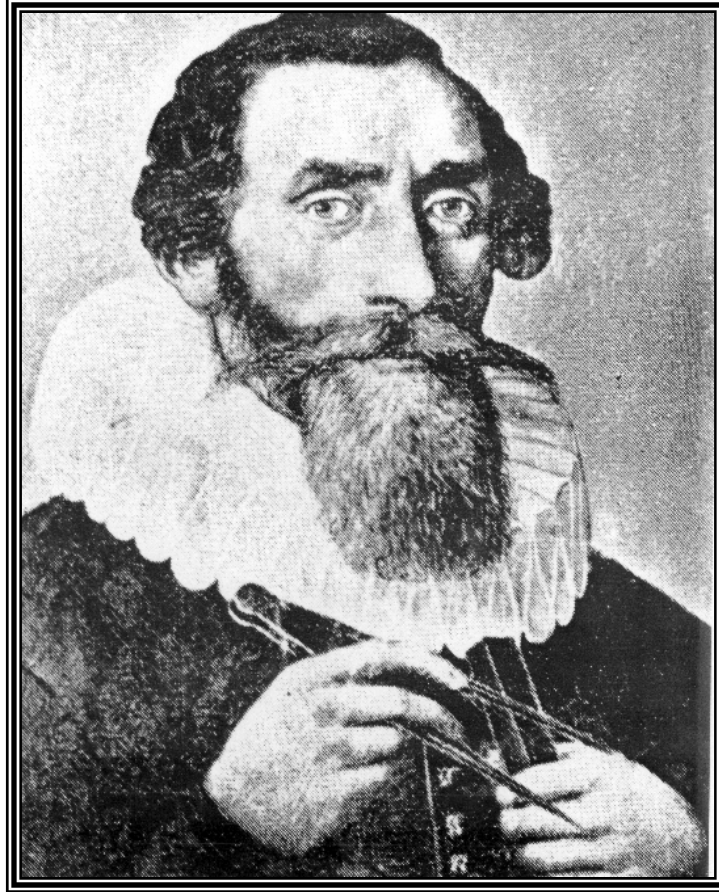
**Erwin Schrödinger (1939)**

**Creation of a single pair of particles  
of undetectably small energy  
somewhere in the universe  
in the next 14 billion years**

***Alarming?***



# *An even earlier Graz cosmologist*



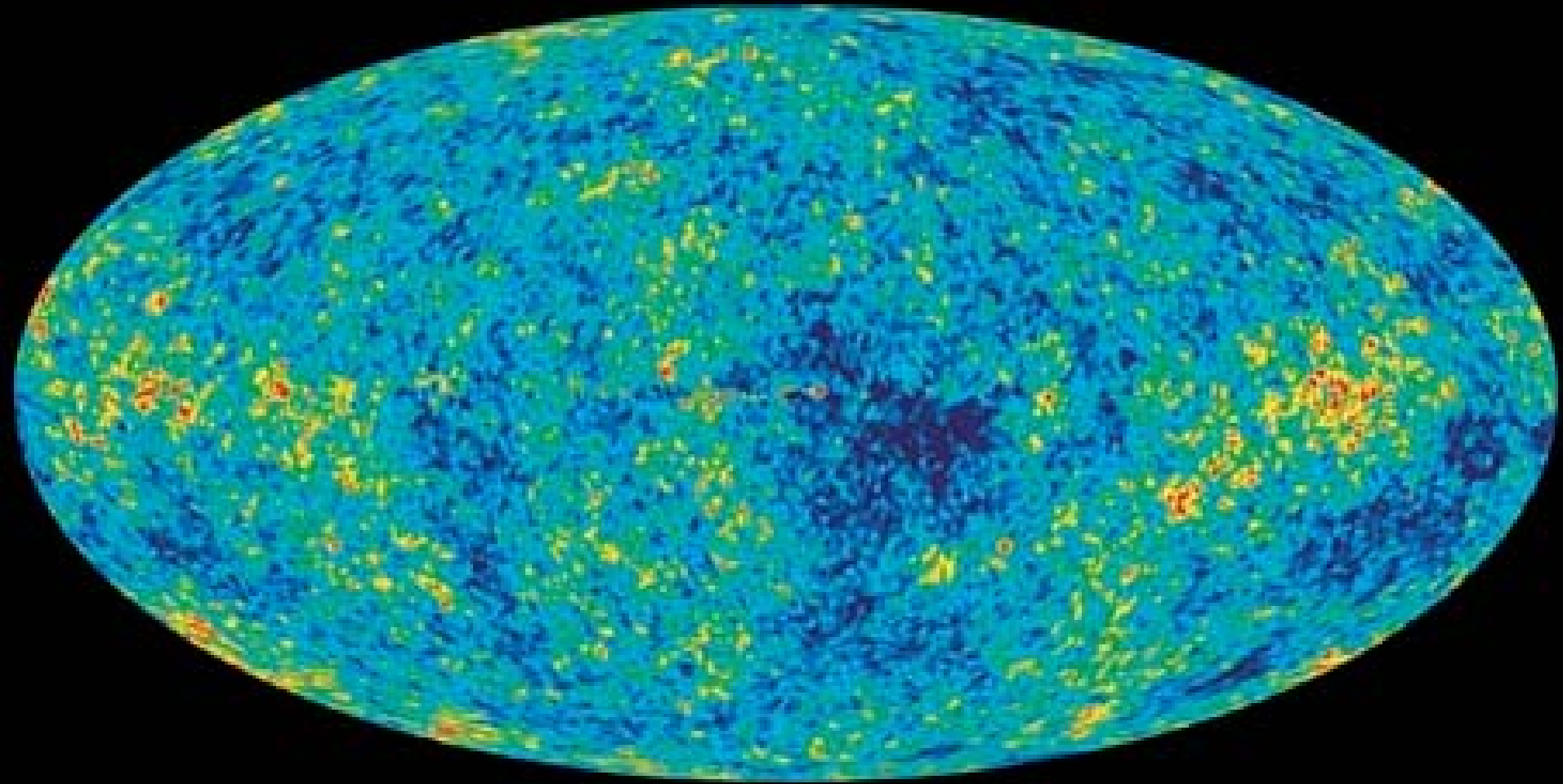
“When the storms rage around us, and the state is threatened by shipwreck, we can do nothing more noble than to lower the anchor of our peaceful studies in the ground of eternity.” - *J. Kepler*

1600-1630: Graz → Prague → Linz → Sagan → Ratisbon



“When the storms rage around us, and the state is threatened by shipwreck, we can do nothing more noble than to lower the anchor of our peaceful studies . . .

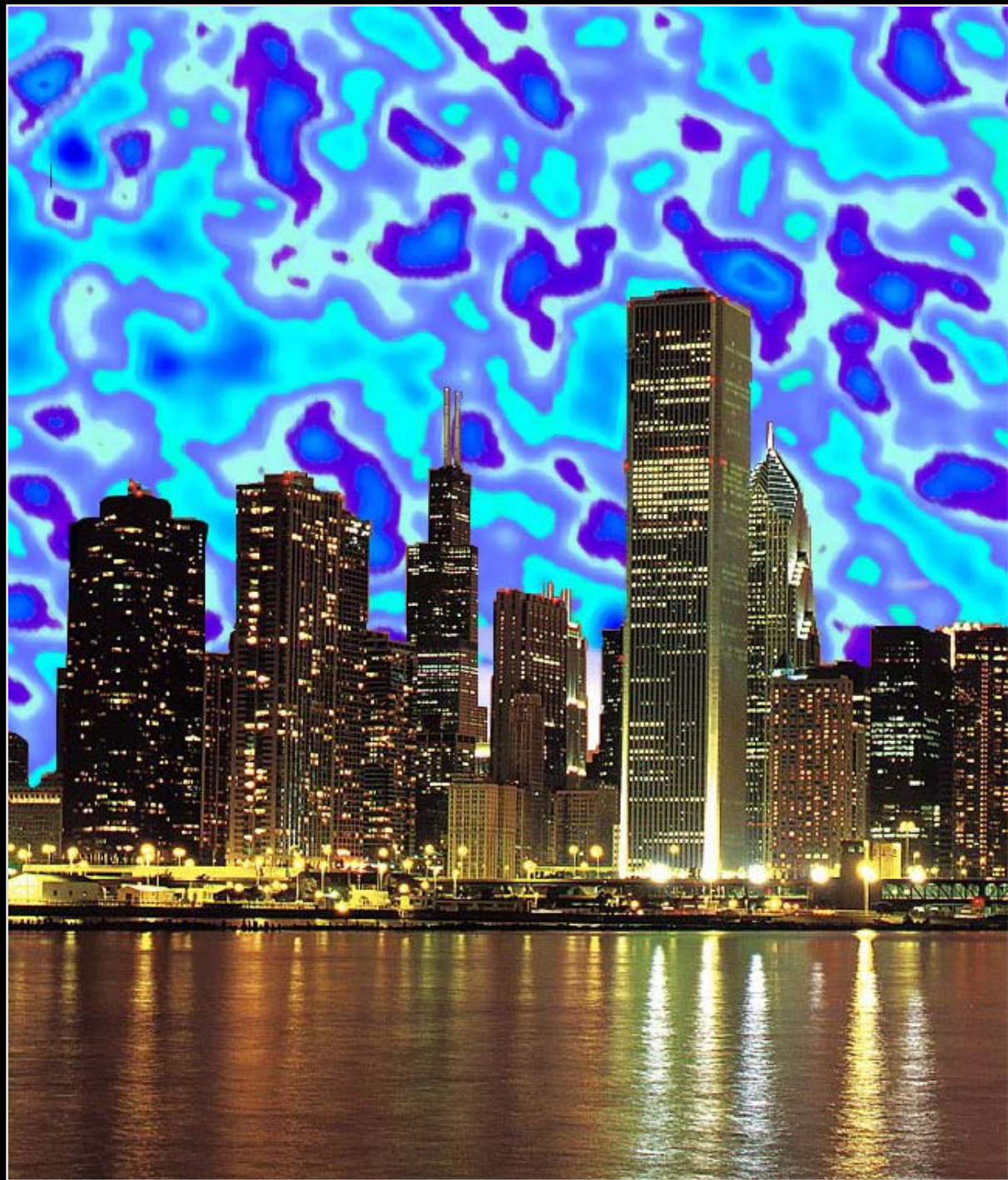
**Quantum uncertainty—inner space**



**Temperature ripples—outer space**

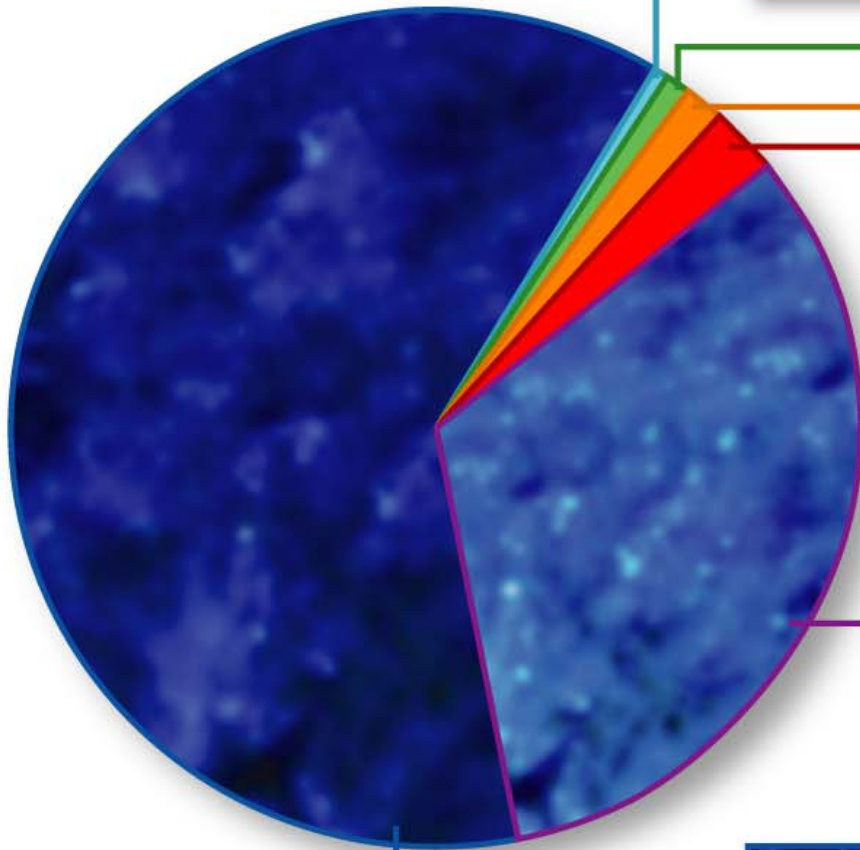


**A pattern  
of  
vacuum  
quantum  
fluctuations  
(the alarming  
phenomenon)**

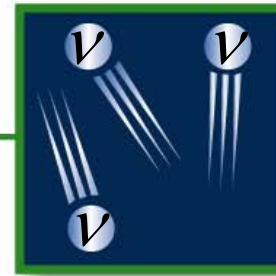




# Cosmic Pie



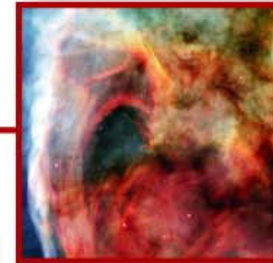
**Chemical Elements:**  
(other than H & He) 0.03%



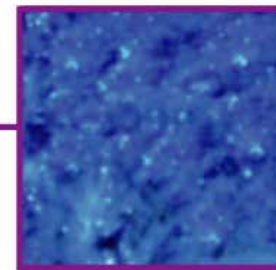
**Neutrinos:**  
0.47%



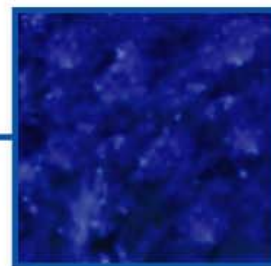
**Stars:**  
0.5%



**Free H  
& He:**  
4%



**Dark Matter:**  
25%



**Dark Energy:**  
70%

**95%**  
***mystery***

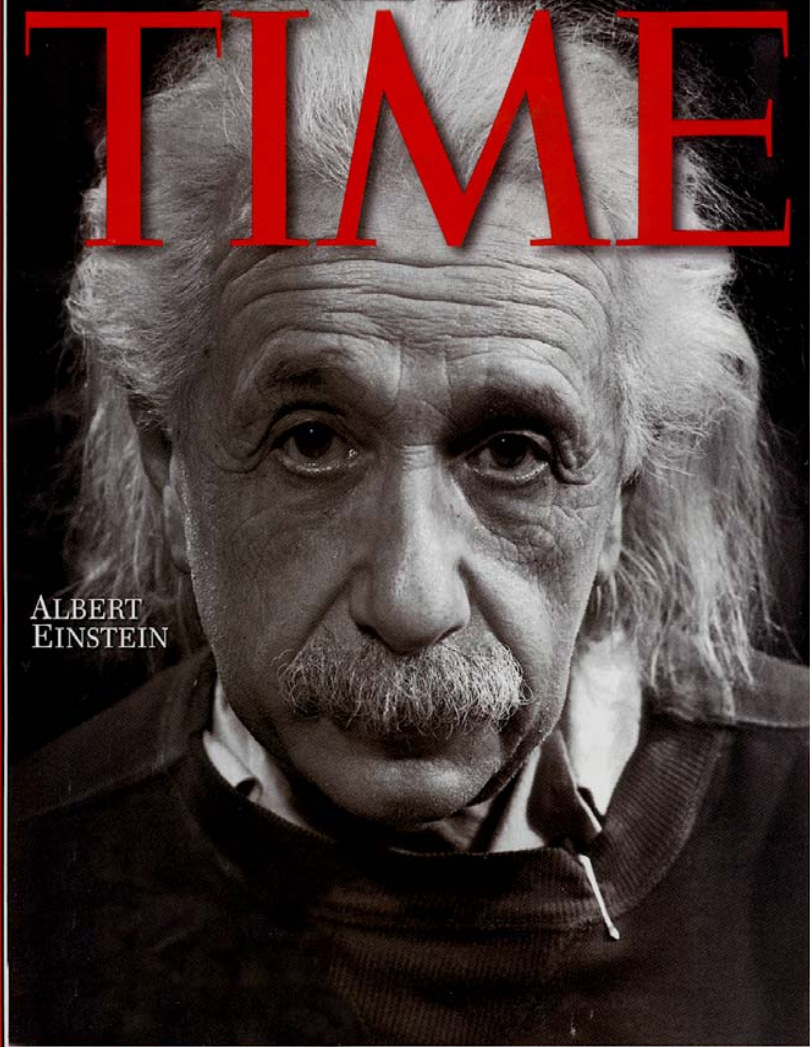
DECEMBER 31, 1999 \$4.95

www.time.com

PERSON OF THE CENTURY

TIME

ALBERT  
EINSTEIN



DECEMBER 31, 2000 \$4.95

www.time.com

PERSON OF THE CENTURY

TIME

?





# *The big bang*

A cosmic funnel diagram. On the left, a narrow, bright orange and yellow cone represents the hot, dense early universe. This cone widens as it moves to the right, where it opens up into a vast, dark space filled with numerous galaxies, including spiral and elliptical ones, representing the expansion and cooling of the universe.

[http://home.fnal.gov/~rocky/summer\\_03.pdf](http://home.fnal.gov/~rocky/summer_03.pdf)

**Rocky Kolb**  
**Fermilab and the**  
**University of Chicago**